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February, 1958

Volume 70 Number 1

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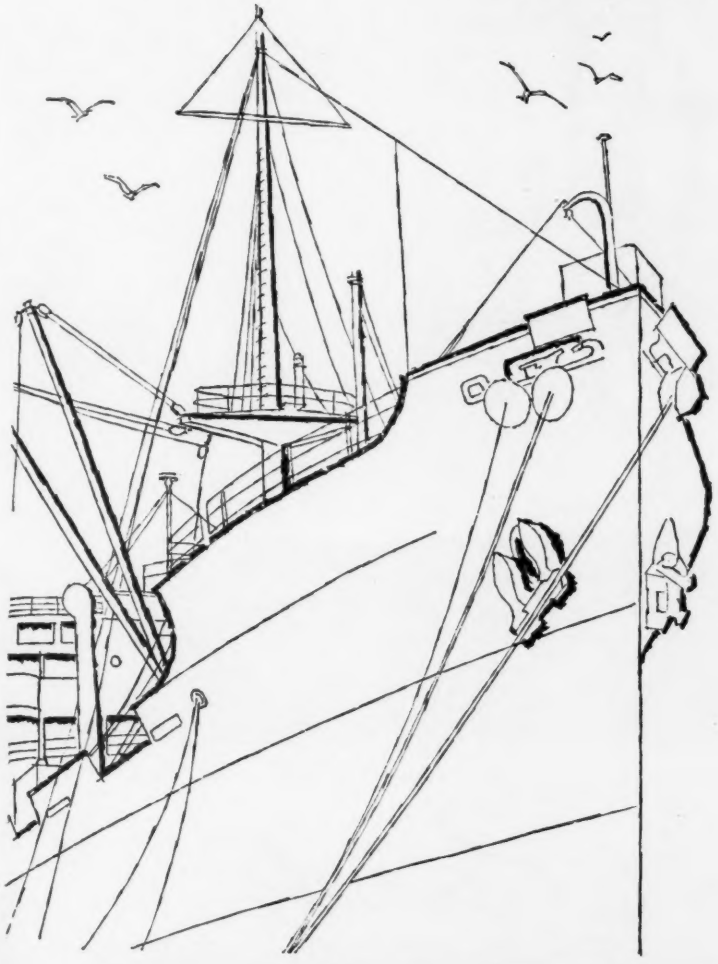

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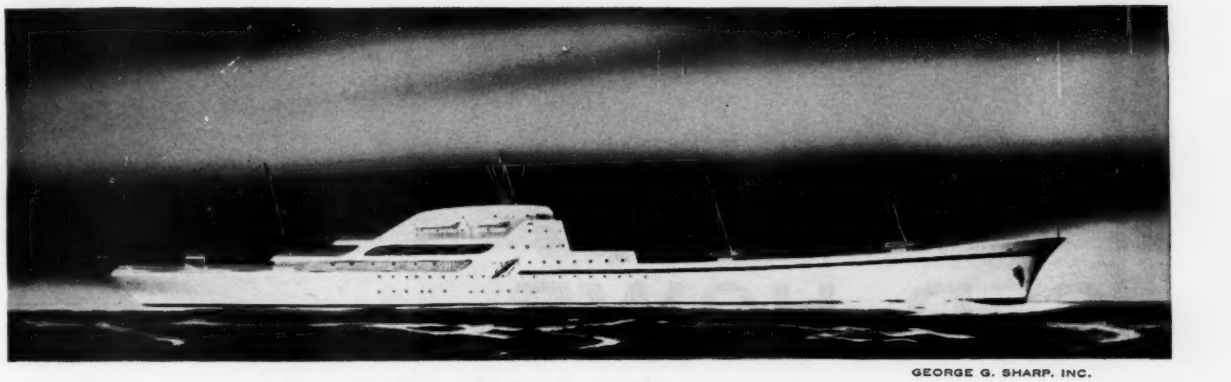

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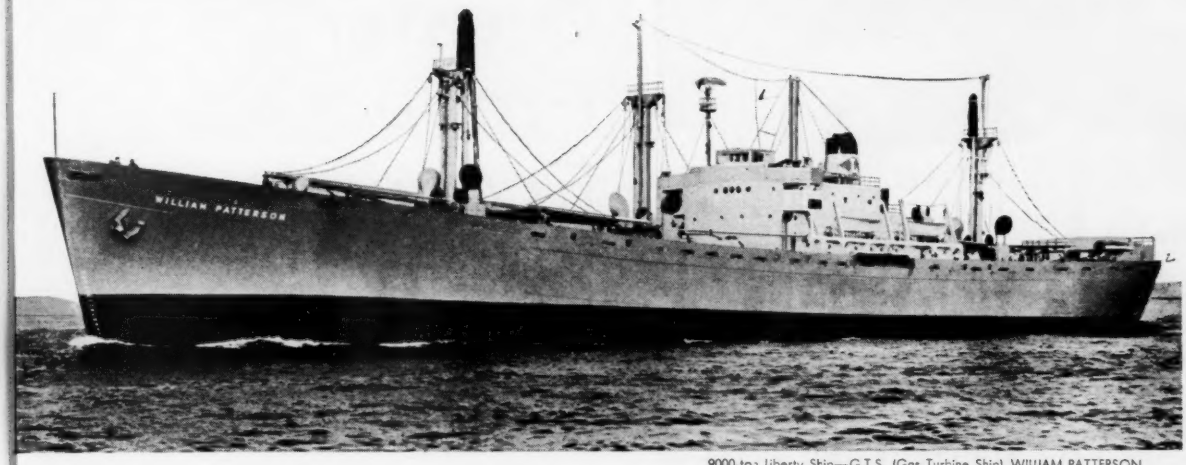

9000-ton Liberty Ship—G.T.S. (Gas Turbine Ship) WILLIAM PATTERSON

First in the United States—and largest of its type in the world—General Motors' new Free-Piston-Gas-Turbine Engine marine installation has successfully passed sea trials in the converted Liberty Ship WILLIAM PATTERSON, which will be operated in transatlantic service for the Government by Lykes Brothers Steamship Company.

This great new marine power plant was engineered and developed by Cleveland Diesel, aided by hundreds of scientists and engineers at General Motors' vast Technical Center in Detroit, other Divisions of General Motors and SEME-SIGMA, France.

It was installed in the WILLIAM PATTERSON by the Bethlehem Steel Company Shipbuilding Division, Baltimore Yard, under the direction of the Office of Ship Repair and Construction, Maritime Administration, U. S. Department of Commerce.

The success of this new Free-Piston-Gas-Turbine power plant marks a big forward step in the Maritime Administration's program to improve the performance standards of America's Liberty Ships.

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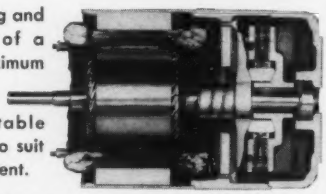

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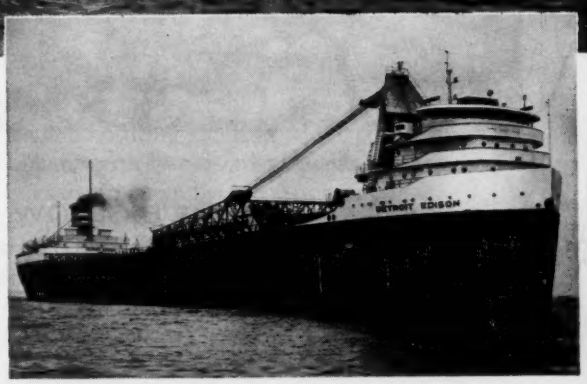

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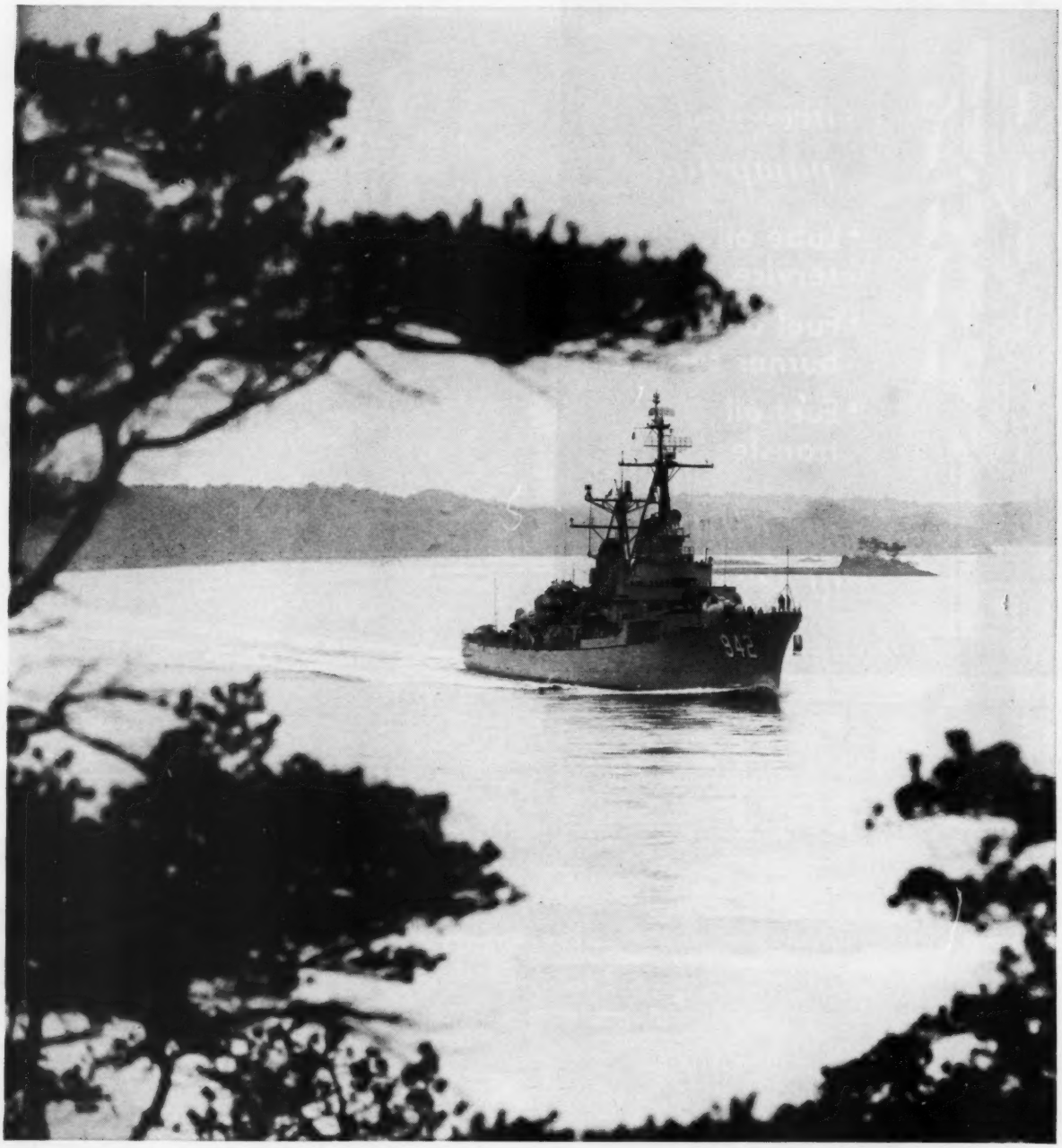

U. S. S. BIGELOW proceeding up the Kennebec
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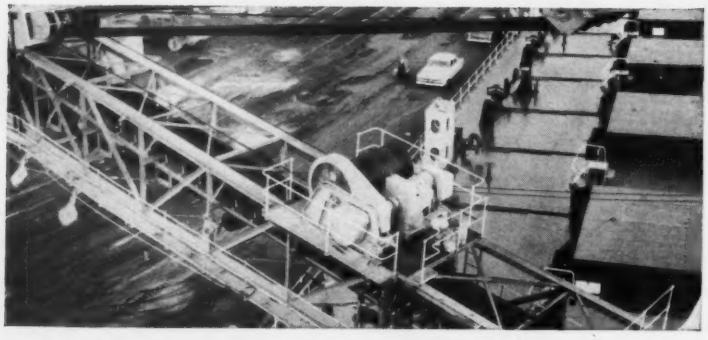

Saves in handling ore: Automatic unloaders carry ore off NBC ships. Monel* alloy pins keep sheaves running free. And Monel ALEMITE® grease fittings in the pins lubricate moving parts. Inside the holds, the gates that control the flow of ore swing on Monel hinge pins.

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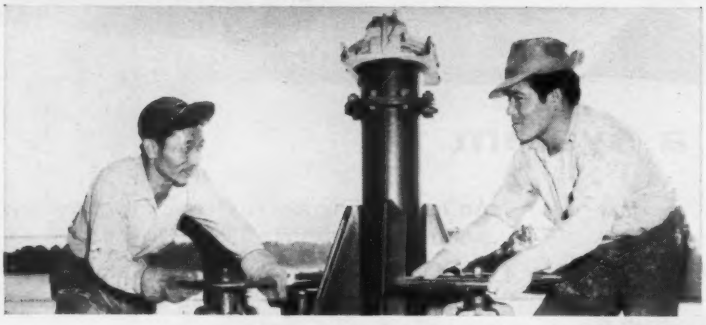

Saves in handling oil: The topside sections of reach rods that control flow of oil on tankers are Monel nickel-copper alloy. Shafts and shaft sleeves in fire pump, main and auxiliary circulating pumps, ballast pump and many other pumps subject to salt water and other corrosive material and severe wear are also Monel alloy. NBC finds that *rugged Monel shafting and sleeves last very much longer.*

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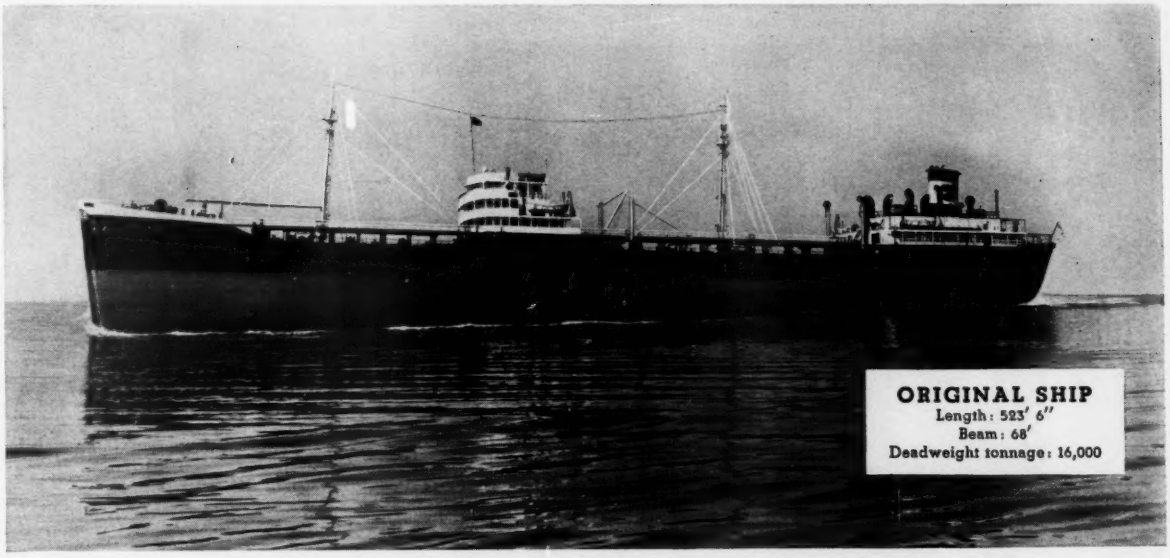
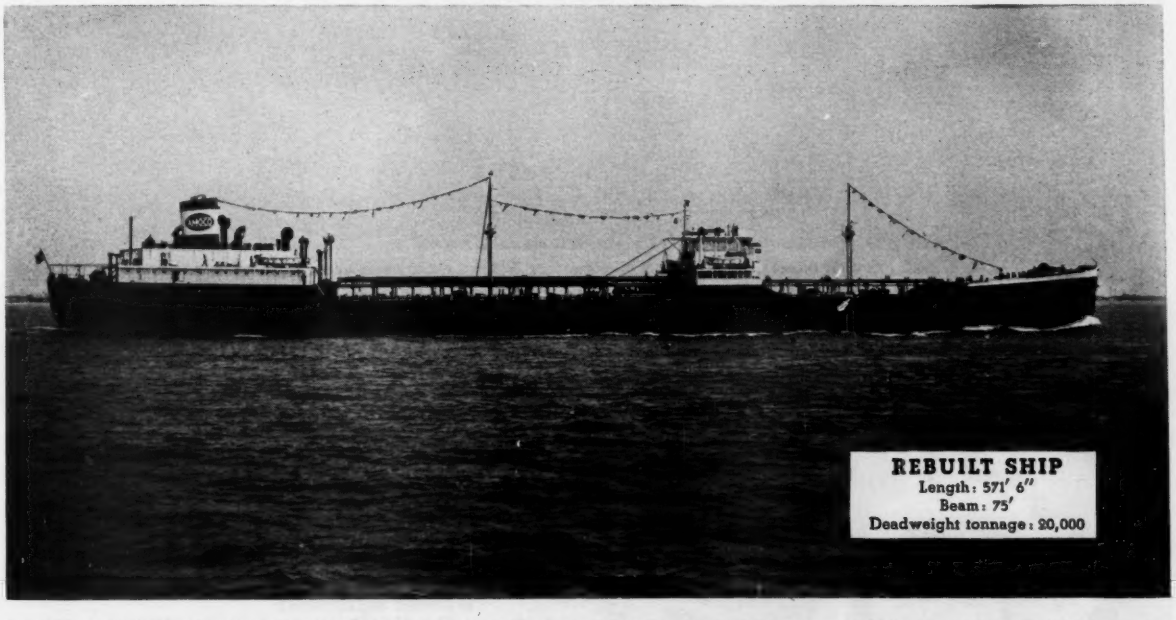


NEWPORT NEWS "JUMBOIZES" WARTIME T-2 TANKER



READ WHAT NEWPORT NEWS IS DOING TO HELP OVERCOME TANKER OBSOLESCENCE

The Amoco Delaware is one of four T-2 tankers to undergo a unique "jumboizing" operation at the Newport News Yard. That required only 42 working days.

Along with other alterations, her cargo tanks were completely replaced with a longer section of wider beam. Three more of these 310-foot sections are building at Newport News to complete conversion of additional tankers.

Enlargement of the DELAWARE, according to Vern Drew, Amoco's General Manager of Marine Operations, resulted in no appreciable loss of speed with the increase in capacity from 16,700 to 20,000 deadweight tons.

"Giving these ships a new life of 15 years," says Mr. Drew, "is one way of beating the block obsolescence of America's tanker fleet."

Operation Jumbo is another example of the "tough" ones at Newport News. And for good reason. Newport News has the fully integrated facilities and the skilled personnel to turn out extensive conversions and alterations in the shortest possible time.

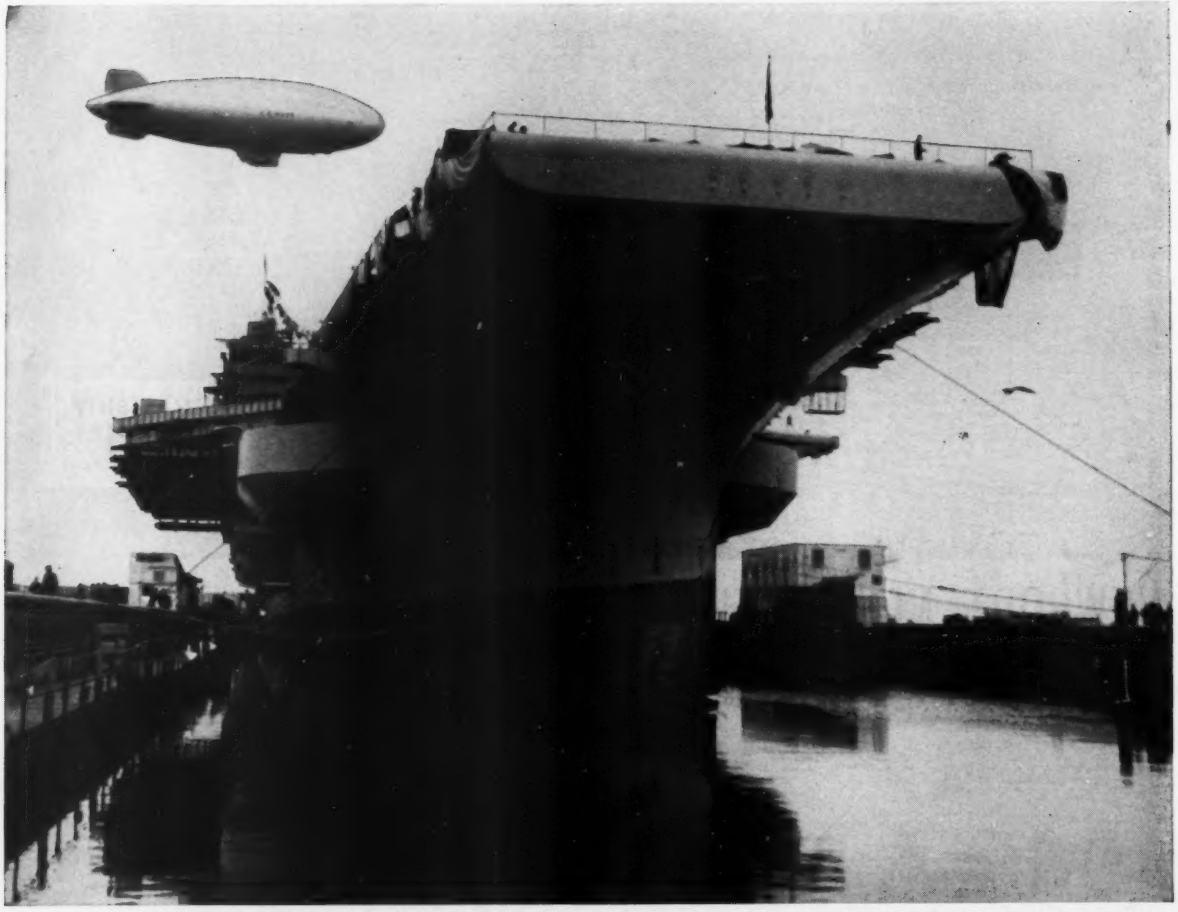
Your inquiries about T-2 conversions are invited.

Engineers . . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

Newport News

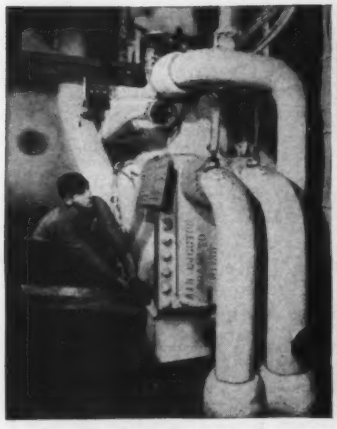
Shipbuilding and Dry Dock Company

Newport News, Virginia

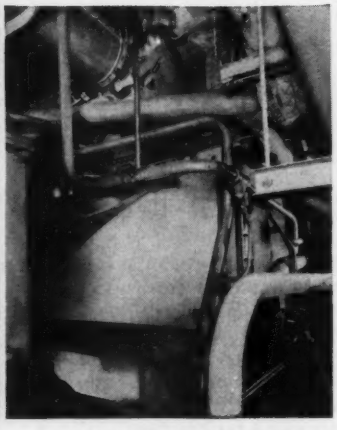


The U.S.S. Forrestal (above) and the U.S.S. Saratoga are both fitted with equipment engineered and built by C. H. Wheeler. The U.S.S. Ranger, the U.S.S. Independence and the U.S.S. Kitty Hawk, now under construction, will also be Wheeler-equipped.

SUPERCARRIERS NEED "SUPER" EQUIPMENT



Vacuum Drain Tank Ejector, built by Wheeler, which has been installed in the U.S.S. Saratoga, sister ship of the U.S.S. Forrestal (above).



Main Condenser (forward) on U.S.S. Saratoga. Nearly all U.S. Navy ships—even atomic submarines and supercarriers—have Wheeler equipment aboard.

The nation's two new "super-equipped" supercarriers now afloat, the U.S.S. Forrestal and U.S.S. Saratoga, contain marine machinery custom-engineered and precision-built by C. H. Wheeler. The three supercarriers which are now under construction, the Independence, the Ranger and the Kitty Hawk, will also use Wheeler equipment.

On the Saratoga are two Wheeler Marine Condensers, which in combination with newly-designed turbines, develop 200,000 horsepower to drive this beautiful 60,000-ton supercarrier in excess of 30 knots. Wheeler Anchor Windlasses, Ordnance Elevators, Capstans, Winches, Auxiliary Gland Exhaust Condensers and Distilling Plant and Vacuum Drain Ejectors are also installed on the 1,040-foot Saratoga.

Marine Division

C-H-Wheeler Mfg·Co·

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Marine Condensers, Ejectors, Pumps and Auxiliary Machinery • Steam Condensers • Vacuum Equipment • Centrifugal, Axial and Mixed Flow Pumps • Nuclear Products

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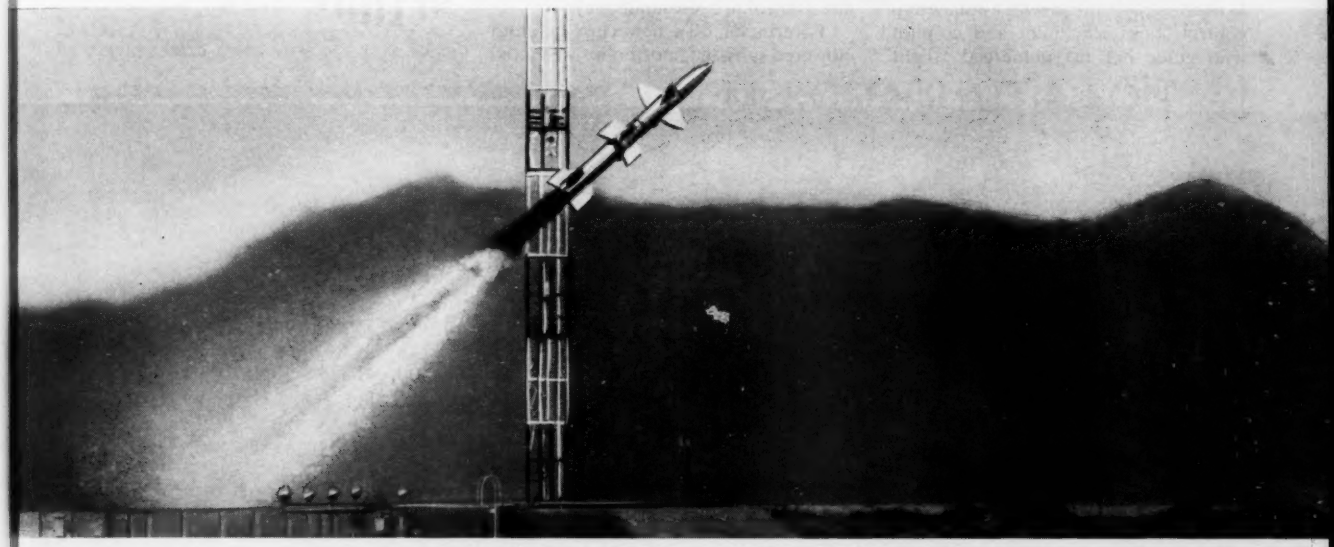
TALOS



This Talos launching from the RCA Defense System on Dec. 13, 1957, resulted in direct hit on distant drone plane.

The RCA Talos Defense System is the first *completely automatic* land-based system for launching and guiding missiles, and utilizes the Talos Missile developed by the Applied Physics Laboratory and produced by Bendix. The Defense Unit receives target signals from remote outposts, analyzes them with regard to number of attackers, location, course and speed. Next, computers determine the logical points of interception, order the missiles loaded on launchers, guide them at supersonic speed to the vicinity of the target, after which the missiles "lock" on the target and close in for its destruction. All without even the touch of a button! The RCA Talos Defense System, with its electronic equipment and guidance systems, was designed, developed and built by RCA as prime contractor, aided by many subcontractors. It was turned over to the U. S. Army on October 15, 1957, and is a missile milestone, exemplifying the continuing determination of American enterprise to secure peace with honor and justice.

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RADIO CORPORATION of AMERICA

DEFENSE ELECTRONIC PRODUCTS

CAMDEN, N. J.

THE STORY BEHIND THE STORY

NEW SUB "FLIES" UNDER WATER

U.S.S. ALBACORE climbs, banks, dives like an airplane

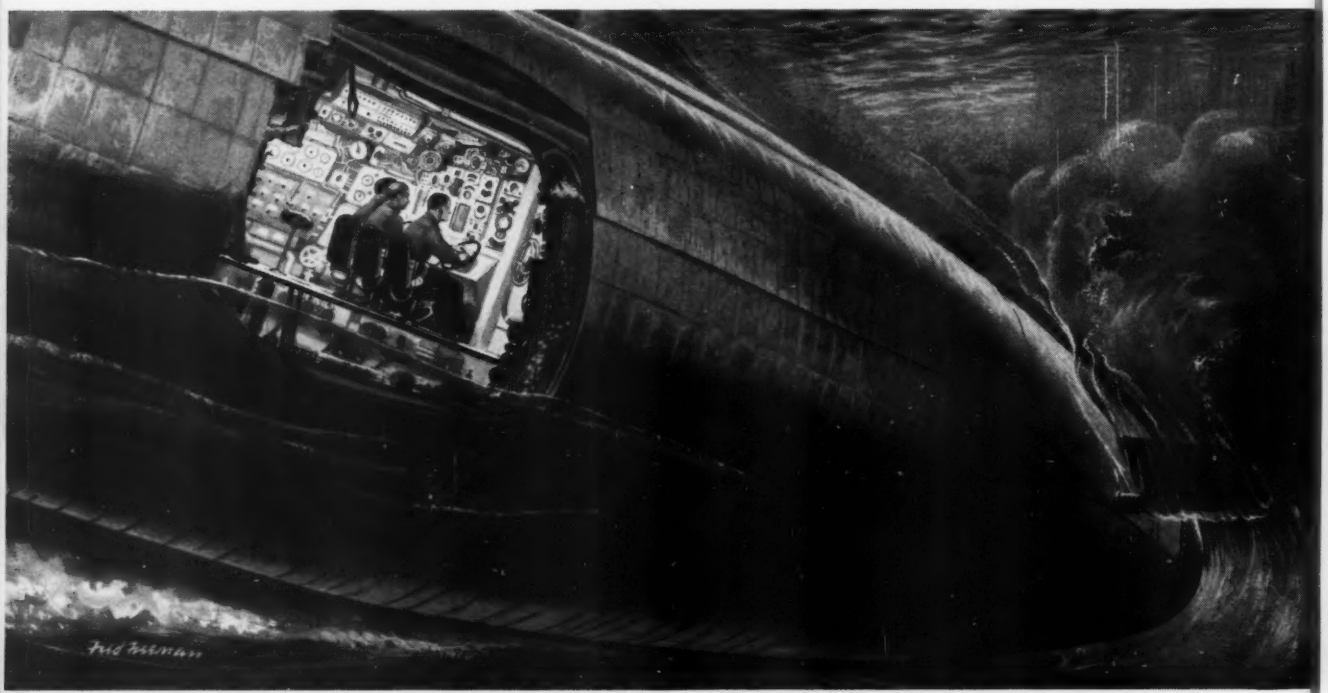
When plans for the ALBACORE were made, the U. S. Navy required a precise and versatile control system for this revolutionary new submarine. As a pioneer for 45 years in instruments and controls for ships as well as aircraft, Sperry was well qualified to handle this assignment. For when submerged the 203-ft. ALBACORE flies like an airplane.

Faster than many ocean liners, the ALBACORE is equipped with airplane-type control sticks for "pilot and co-pilot" who guide her in submerged "flight" with the help of an automatic pilot. Sperry instruments for diving and course-keeping controls are integrated to provide all the data needed for automatic, "feather-touch" control in many maneuvers. With this equipment, a pilot, co-pilot and a control engineer do the job it takes additional men to perform in a conventional sub. Sperry programs to facilitate submarine navigation and fire control are also underway.

Forerunner of a new class of atom-powered subs, the unorthodox ALBACORE is now serving as a research laboratory for testing the combat utility of her unique hull, design, propulsive equipment and, of course, her Sperry instrumentation. Early reports show that, like the Sperry control systems aboard the B-52 jet bomber and the Navy's Skywarrior A3D attack bomber, it affords precise and positive control of this boat that flies like a plane.

SPERRY GYROSCOPE COMPANY
Great Neck, New York

DIVISION OF SPERRY RAND CORPORATION



Cutaway view above shows ALBACORE's flight control station, with pilot and co-pilot at control sticks. Blimp-like hull of sub follows aerodynamic principles governing design of aircraft in order to permit "hydrobatic" maneuvers.

(1) **Climbing fast,** proposed ALBACORE-type submarine could (2) erupt on surface, (3) launch rockets or missile against enemy, then (4) submerge to flash away (5) in steep turning dive and (6) proceed to next target. Sub has faster turning rate than jet.

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Turbines ranging from 5 to 3000 H.P. are built in the Terry Solid Wheel design as well as in the Axial Flow, single stage and multistage types.

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EFFICIENCY . . . ECONOMY

Cooper-Bessemer heavy-duty diesel engines furnish dependable power for Navy and Coast Guard vessels ranging in size from large combat ships to relatively small patrol boats. Marine men everywhere have respect for the smooth, fast response, and high over-all operating efficiency which are standard with every Cooper-Bessemer Diesel engine. Find out for yourself the *new* things now being done by one of America's *oldest* engine builders. Write for detailed information.

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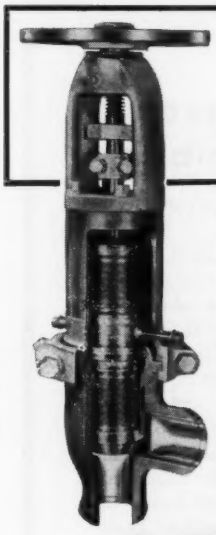

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brings this new look in valves

This is the type of valve found in the engine rooms of the *Nautilus* and the *Seawolf*, and in Navy's plans for added atomic-powered construction. The valve design and application are new, but the brand is well known for dependability.

From the start of nuclear power development, Crane was ready for the problems of controlling radioactive fluids. Crane had the skill in valve metallurgy and engineering. Crane had the background in quality production.

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NAVAL ARCHITECTS

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25 Years' Experience has proved the Value of Arsenic as an Inhibitor

Research at The American Brass Company nearly 25 years ago showed that about 0.04% arsenic would inhibit dezincification of brass, and this amount of the element has been added to Admiralty metal and aluminum brass since then.

MARINE USERS generally find ANACONDA Arsenical Admiralty-439 satisfactory for inland-water vessels and also for seagoing vessels where service conditions are moderate; but ANACONDA Ambraloy-927 is preferred for most seagoing vessels. Both alloys are resistant to dezincification under all corrosive conditions found in these services.

YOUR OWN NEEDS may call for these corrosion-resistant Anaconda alloys or they may call for other tube alloys we make. Our Technical Department will be glad to help you select the one best alloy for the conditions you face.

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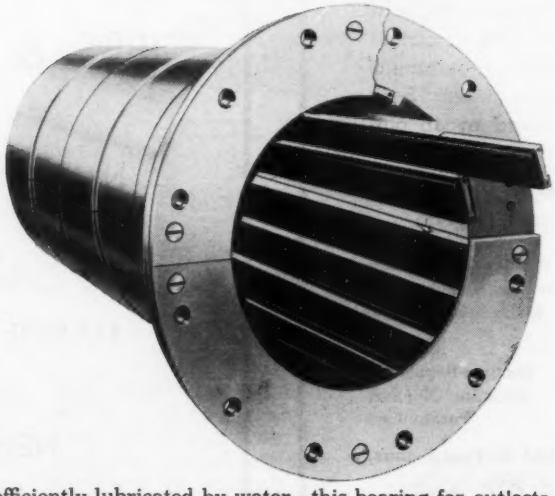

Soft rubber bearing surface—efficiently lubricated by water—this bearing far outlasts all hard surface types, protects propeller shafts, reduces vibration. More than pays for itself in extra wear alone. Saves you time, trouble, and upkeep expense.

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THE 1958 ANNUAL BANQUET

of

The American Society of Naval Engineers

will be held at

HOTEL STATLER

WASHINGTON, D. C.

on

Friday, 2 May 1958.

Notices with application forms soon will be mailed to all members.

REAR ADMIRAL LEROY V. HONSINGER, U. S. NAVY
President for 1958

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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 70 FEBRUARY, 1958 NUMBER 1

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COUNCIL OF THE SOCIETY

(Under whose supervision this number is published)

Rear Admiral LEROY V. HONSINGER, USN, President

Captain JAMIE ADAIR, USN
Mr. JOHN B. ARMSTRONG
Mr. HUGH E. CARLETON
Captain JOSEPH A. HARTMAN, USNR
Captain IVAN MONK, USN
Captain LOUIS H. RODDIS, USNR
Captain RICHARD D. SCHMIDTMAN, USCG
Rear Admiral PHILIP W. SNYDER, USN
Captain E. A. WRIGHT, USN

Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer

SECRETARY'S NOTES

Joint Council Meeting

The annual meeting of the members of the 1957 and 1958 Councils was held on Thursday, 2 January 1958. The photograph on page 6 was taken on this occasion. A certificate of Honorary Membership was presented to the retiring President, Rear Admiral Albert G. Mumma, U. S. Navy and a certificate of election was presented to the incoming President, Rear Admiral Leroy V. Honsinger, U. S. Navy.

Annual Election

Mr. David B. McAuley, chairman of the ballot counting committee, presented the results of the annual election at which 1565 votes were cast.

The President declared that, from the ballot count, the candidates whose names in the table below are marked with an asterisk(*) had been elected.

Filling of Vacancy

To fill the vacancy which was created by the sad death of Vice Admiral Bernard E. Manseau, USN, Retired, the Council appointed Captain Jamie Adair, U. S. Navy. Captain Adair's term of office will expire on 31 December 1958.

Composition of Council

The Council of the Society for 1958 will be composed as follows:

*Rear Admiral Leroy V. Honsinger, U. S. Navy, President 1958
Captain Jamie Adair, U.S. Navy Term expires 31 Dec. 1958

Mr. John B. Armstrong Term expires 31 Dec. 1958
*Mr. Hugh E. Carleton Term expires 31 Dec. 1959
Captain Joseph A. Hartman, USNR Term expires 31 Dec. 1958
*Captain Ivan Monk, U.S. Navy Term expires 31 Dec. 1959
*Captain Louis H. Roddis, USNR Term expires 31 Dec. 1959
*Captain R. D. Schmidtman, USCG Term expires 31 Dec. 1959
*Rear Admiral Philip W. Snyder, U. S. Navy Term expires 31 Dec. 1959
Captain E. A. Wright, U. S. Navy Term expires 31 Dec. 1958
*Captain J. E. Hamilton, USN (Ret.) Secretary-Treasurer 1958.

ASNE Staff

The Council approved continuing in 1958 with the same staff personnel as have been so ably carrying on our work. Captain R. B. Madden, U. S. Navy was reappointed Assistant Secretary-Treasurer thereby assuring, for another year, the quality of the reprinted articles which are selected to appear in the JOURNAL as well as the many other great assists which the Secretary-Treasurer has been favored with for several years in both his administrative and editorial tasks. As to Mr. Arthur G. Fessenden, about whose devotion and valuable service to the Society, now just a few months shy of half a century, we can never say too much, he will continue as Administrative Assistant. He will be assisted by Miss Ruth Leonard as bookkeeper and Mrs. Virginia Burns as Clerk-Stenographer.

Budget

As required by a recent change in the by-laws, the Secretary-Treasurer submitted a budget for 1958. This was accepted by the Council and in summary is as follows:

Income

Membership	$31,875.00
Advertising	10,000.00
Subscriptions and Sales	16,383.50
Banquet	28,800.00
Interest on investments	1,400.00
Total Income	$88,458.50

Expenditures

Overhead	$26,800.00
Taxes	351.00
Awards	600.00
Membership List	1,800.00
Banquet	25,000.00
The Journal	33,600.00
Total Expenditures	$88,151.00
Indicated Profit	$ 307.50

This budget has been conservatively figured and, although the indicated profit is very small, it is in a black figure which has not shown up in our accounts for several years.

ASNE Award

Each voting member of the Society is aware of the move which has been underway to create an ASNE Award. A questionnaire on this subject was mailed with the ballots and the response was surprisingly heavy and favorable and consistent. In the lead article on page 7, we present this story and its meaning, to the full membership.

Membership List

With this issue of the JOURNAL, a new list of members is being mailed to each member of the Society. We have made every effort to print a correct list as of 1 February 1958. Nonetheless it is inevitable that there are inaccuracies in the Society's records, due in part at least to the apparent reluctance of many members to advise us of changes in position, in title or in address. We hope that each member will check his entry in the Membership List and will let us know without delay of anything printed which is not correct.

We believe that we are reflecting the views of all members, in adhering to the old American belief in the importance of the individual. This is evidenced by the retention of original Society rules that there shall be no company membership and by the requirement that each member or guest who attends the annual banquet shall be individually named in advance. Because of this policy a *correct* list of members is considered to be essential. How this list can be kept correct without the fullest cooperation of the individual members is a problem whose solution has baffled us.

Cost of Reprints

Recently we have received several orders for small lots of reprints of JOURNAL articles *after* the JOURNAL was printed. This is hard to avoid since there is no way for anyone, except the Society staff, the author and those whom are told in advance by the author, to know that an article is going to be published. The cost of these "post-run" orders is running very high, in one case of 150 copies 70 cents per copy compared with 24 cents for the same number concurrently run. Because of this high cost we have absorbed a part but will not be able to continue this practice. We suggest that any author who believes that reprints of his articles will be wanted take personal steps to see that the order is placed with us about 30 days before the publication date. The saving to the purchaser will be appreciable.

Long-Time Members

In the November 1957 JOURNAL we published, under this head, a list of those whose membership in the Society had endured for 45 years or more. In compiling this list we used the old ledgers which we knew to be somewhat incomplete. Although this may have caused several errors, only one has been brought to our attention.

The list showed that Mr. Ernest H. B. Anderson had joined the Society in 1908. A search of other records indicate that he was a member in 1907 which, of course, puts him into the 50 year class as of 1957. We regret errors of this kind and are doing our best to obviate them in the year 2008 when the current records may be referred to.

Armed Forces Day

We want to cooperate with the Department of Defense in publicizing Armed Forces Day. This cooperation may lack effectiveness because our publication dates and the day selected for observance do not mesh too well. This issue is almost three months ahead—the next issue is eight days behind. Early though it may be we publish the following proclamation and ask our members to fix the date of 17 May 1958 in their memories, and to act as best they can to make this day a success.

"THE WHITE HOUSE
ARMED FORCES DAY

* * *

BY THE PRESIDENT
OF THE UNITED STATES OF AMERICA
A PROCLAMATION

WHEREAS the armed forces of the United States manifest our strength and our determination to maintain our national freedom and security; and

WHEREAS members of the active and reserve components of the armed forces of the United States are engaged in programs designed to demonstrate to all the peoples of the world our purpose to uphold and defend the free way of life; and

WHEREAS the year 1957 marks the tenth anniversary of the unification of our armed forces under the National Security Act of 1957; and

WHEREAS it is appropriate that we dedicate one day each year to paying special tribute to the members of our armed forces, and that on such day the armed forces demonstrate to the people of the Nation their operations and capabilities; and

WHEREAS it is also appropriate that the public be invited to visit on that day, within the limits permitted by security requirements, the posts, camps, stations, bases, vessels, armories, reserve centers, and other facilities:

NOW, THEREFORE, I, DWIGHT D. EISENHOWER, President of the United States of America and Commander in Chief of the armed forces of the United States, do hereby proclaim the third Saturday of May in 1957 and the third Saturday of May in each succeeding year as Armed Forces Day; and I direct the Secretary of Defense on behalf of the Army, the Navy, and the Air Force, and the Secretary of the Treasury on behalf of the Coast Guard, to mark that day each year with appropriate ceremonies, to arrange for demonstrations and displays at armed-forces installations, to invite participation by representatives of all religious faiths in such ceremonies, in order that the interdependence of the deep and abiding religious faith of Americans and our security may be recognized, and to work hand in hand with civil authorities in arranging other supporting activities. I further direct the Secretary of Defense, as my personal representative, to assume the responsibility for initiating, formulating, and supervising policies and procedures in keeping with this proclamation.

I also invite the Governors of the States, Territories, and possessions of the United States to provide for the observance of Armed Forces Day each year in such manner as will afford an opportunity for the people of the United States to become better acquainted with their armed forces, both active and reserve.

And I call upon my fellow citizens to display the flag of the United States on Armed Forces Day, in recognition of the sacrifice and devotion to duty of the members of the armed forces.

IN WITNESS WHEREOF, I have hereunto set my hand and caused the Seal of the United States of America to be affixed.

DONE at the City of Washington this fifth day of March in the year of our Lord nineteen hundred and fifty-seven, and of the Independence of the United States of America the one hundred and eighty-first.

(SEAL)

DWIGHT D. EISENHOWER

BY THE PRESIDENT:
JOHN FOSTER DULLES
Secretary of State"

"The New Navy—Mobile Power for Peace"

This is a book notice but we want it to appear more prominently than if set 200 pages farther back. The United States Naval Institute has published and sells for 50 cents, a 40 page booklet, profusely illustrated to describe the "what" and "why" of today's Navy. The Naval Institute describes it this way:

"Here, in forty pages, packed with information, maps, charts, and photographs, is the succinct summary of the Navy's part in the global strategy of the times. For anyone interested in naval affairs, this booklet is of genuine significance. For professional Naval Personnel and Naval Reservists, it provides exactly the pointed pertinent information necessary to a better understanding of their Navy's role in today's national and international picture. (Though just published, THE NEW NAVY is already on the required reading list for promotion to Captain.)"

Seated: Left to right: Captain Schmidtman, 1958-9 Council; Captain Wright 1957-8 Council; Captain Hartman 1957-8 Council; Capt. Ayres, 1957 Council; Rear Admiral Honsinger, 1958 President; Rear Admiral Mumma, 1957 President; Mr. Armstrong, 1957-8 Council; Capt. Horn, 1957 Council; Mr. Shepard 1957 Council.

Standing: Left to right: Captain Hamilton, Sec.-Treas.; Mr. McAuley, Chairman, Ballot Committee; Captain Adair, 1958 Council, Captain Roddis, 1958-9 Council; Rear Admiral Snyder, 1958-9 Council; Captain Madden, Assistant Sec.-Treas.; Mr. Fessenden, Administrative Assistant; Mr. Carleton, 1958-9 Council; Captain Monk, 1958-9 Council.

A. S. N. E. AWARD

THE AMERICAN SOCIETY OF NAVAL ENGINEERS is 70 years old in 1958. Only six other technical societies in the United States have attained this age. This year we join the ranks of both older and younger technical groups which periodically recognize an outstanding member of their profession as a symbol of the purpose of the Society. This symbolism ties together the name of an honorable society and that of an individual who has brought national or world-wide honor to its and his profession.

Although of recent years a few academic degrees of "Naval Engineer" have been awarded; for 70 years thousands of naval officers and civilians have joined this Society and thereby become "Naval Engineers," neither of these formal entitlements adequately embraces the profession of naval engineering. In establishing the A.S.N.E. Award we have tried to write a satisfactory definition of "Naval Engineer."

About a year ago, the President, Admiral Mumma, proposed that some sort of senior award be set up. He appointed Captains E. A. Wright, USN and J. A. Hartman, USNR to study the matter and to report to the Council. This committee wanted an expression of opinion from the members of the Society and prepared a questionnaire which members have seen and a surprisingly large number, 1265 of you, filled out and returned. The returns of the questionnaire proved beyond doubt that the members want to make an award and are pretty consistent on how they want it done. The report of the Committee makes this clear.

REPORT OF COMMITTEE ON ASNE AWARD

1. As a result of the questionnaire sent to all members of the American Society of Naval Engineers, 1265 were completed and returned to the Secretary—
2. In summary, the majority of the Society favors:
   (a) Establishing an award.
   (b) Not restricting the award to members of the Society.
   (c) Making the award to any naval engineer who is a United States citizen.
   (d) Basing the selection on any technical writing, invention, design, or other contribution in the field of naval engineering.
   (e) Naming it the ASNE Award.
   (f) Making the award annually.
   (g) Awarding a Gold Medal appropriately inscribed together with a Life Membership in the Society.
   (h) Seeking nominations through the Secretary-Treasurer and at annual meeting and receiving nominations up through the last day of February for the previous calendar year.
   (i) Considering nominations through a committee of 3 members appointed by the President which shall submit recommendations to the Council not later than 31 March.
   (j) Inviting the awardee as a guest of the Society to the Annual Banquet and defraying his expenses if necessary.
3. Impressive features of the questionnaire were:
   (a) The large response indicative of strong general interest.
   (b) An overwhelming majority in favor of establishing an award.
   (c) The general concurrence in the mechanics of the operation.
4. The undersigned recommend that the consensus as revealed by the questionnaire be implemented.

Signed E. A. WRIGHT
J. A. HARTMAN

At the joint Council meeting on 2 January 1958, after receiving the committee's report and full discussion the following resolution was adopted:

RESOLVED

that, annually, if a qualified candidate is found, the Society will award a gold medal and Life Membership in the Society to that naval engineer, military or civilian, who is a citizen of the United States, who in the opinion of the Council has made the most outstanding contribution in the field of Naval Engineering during the preceding year. The details of the award will be approved by the Council and will be published in the JOURNAL for February 1958.

The "details" which were approved by the Council are:

DETAILS OF MAKING ASNE AWARD

The gold medal shall bear the seal of the Society on its face and "American Society of Naval Engineers Award," the year and the name of the recipient engraved on the back.

Nominations will be accepted from:

(a) Any member of the Society through notice in the Journal.

(b) The following, as individuals in their official positions, through letters of solicitation by the Secretary-Treasurer:

- The President of the Society
- The Chiefs of the Navy Bureaus of Ships, Ordnance, Aeronautics, Supplies and Accounts, and Yards and Docks
- The Chief of Naval Research
- The Chief of Naval Material
- The Deputy Chief of Naval Operations for Logistics
- All Type Commanders of both Fleets
- Commanders of Naval Shipyards and Laboratories
- The Engineer in Chief of the Coast Guard
- The Maritime Administrator
- The Assistant Chief of the Bureau of Personnel for Naval Reserve Affairs.

The award shall recognize a truly outstanding accomplishment which is in the field of Naval Engineering and may be a technical writing, invention, design or other contribution in the field of naval engineering.

Nominations shall be in writing and shall set forth in detail the citation for which the award is recommended. All citations must reach the Secretary-Treasurer not later than 15 March, 1958.

The President shall appoint a committee composed of three past Presidents, or, if these cannot be found in the vicinity of Washington, past members of the Council. This committee shall receive all citations of nomination and shall report to the President not later than 1 April the name of their recommended awardee or that there are no candidates deserving of the award. After approval by the Council the Secretary-Treasurer shall notify the awardee, shall arrange for his attendance at the banquet and shall have the gold medal and the certificate of Life Membership prepared.

To carry out his part of soliciting nominations, the Secretary-Treasurer wrote this letter to the people who are listed above:

My dear Sir:

The American Society of Naval Engineers has established an award to consist of a suitably inscribed gold medal and a Life Membership in the Society to be awarded annually to a Naval Engineer who is a citizen of the United States for an outstanding contribution in the field of Naval Engineering.

We solicit your help in selecting this outstanding Naval Engineer. He may be either a military person or civilian who qualifies as an engineer whose applicaton of his profession is in affairs which are connected with the Navy. Your nominee may be a member of your organization or some other person whom you consider to be qualified.

The outstanding contribution must have been made during 1957. It may be an act, a technical writing, an invention, a design or anything else which in your opinion is a professional contribution to naval engineering which, of course, is a very broad field.

Please submit any nomination which you believe to meet the criteria, with name, title and address and a detailed citation, in writing, of his accomplishment to reach

The Secretary-Treasurer,
American Society of Naval Engineers, Inc.
Suite 1004-1012 14th Street, N.W.,
Washington 5, D.C.

not later than 15 March, 1958.

Your citation must, of course, be sufficiently extensive to permit a committee to make a judgement.

Your assistance in this matter will be greatly appreciated.

I am

Very sincerely yours,
American Society of Naval Engineers, Inc.

J. E. HAMILTON
Secretary-Treasurer

TO ALL MEMBERS

Please consider that the letter just quoted is addressed to you. We realize that there is very little time in which to act but if any of you have a candidate for the 1957 A.S.N.E. award please get your citation in our hands before 15 March 1958.

CAPTAIN E. A. WRIGHT, US Navy

SOME INTERNATIONAL ASPECTS OF SHIP MODEL RESEARCH

THE AUTHOR

is an Engineering Duty Officer who has served 7 years in the United States Fleet, 6 years in naval shipyards, 4 years in warship design, and 6 years in a naval laboratory. He is presently Commanding Officer and Director of the David Taylor Model Basin, and a member of Council of this Society.

EDITOR'S NOTE

Proceeds from this article have been deposited as a "Host Fund" for international visitors to the David Taylor Model Basin.

Ship model research since mid-century has experienced a strong surge throughout the maritime nations of the world. The purpose of this paper is to recognize some of the international growth of possible interest to naval engineers.

The observations are based largely on the International Towing Tank Conference in Madrid, visits to most of the principal European model basins, and the Symposium on Behavior of Ships in a Seaway held at the Netherlands Ship Model Basin, all during September 1957.

I. CONCLUSIONS

WHAT GROWTH is evident in the model basin business abroad and how is the United States doing comparatively? In response to this most frequent question, a few general conclusions are:

a. Widespread construction of new facilities for ship model research is occurring throughout the world. In summary, the number presently under construction or completed since World War II is as follows:

TYPE OF FACILITY	NUMBER
Rotating Arm Basins	7
Seakeeping and Maneuvering Basins	8
Towing Tanks—New	25
Extended	3
Shallow Water Basins and Flow Channels	12
Cavitation Tunnels	15

b. From a purely plant standpoint, foreign model basins momentarily lead the United States in rotating arm basins, seakeeping basins, shallow water basins, and cavitation tunnels, but current building at Carderock will go far to restore our position.

c. General purpose digital computers are an indispensable adjunct to model research in the future, and in the United States relatively great progress has been made in their application.

d. The growth of model basin facilities in association with universities at home and abroad is already proving its wisdom.

e. Ship model research in all countries is now as always wholly dependent on dedicated scientific and engineering personnel with unfettered imagination and applied enthusiasm. Without them, funds and facilities are meaningless.

f. Model basin professionals abroad are highly alert, curious, cosmopolitan, modest, helpful, competent, and progressive. Much is being accomplished by a few.

g. Contributions by the younger set in all delegations to the conferences were particularly impressive.

h. The quality of research in all model basins visited appeared high, but no more so than in the United States.

i. Science has come to naval architecture on a fine broad international front, particularly in stormy fields such as the wavegoing aspects of seakeeping.

j. The concurrent development of theory and experiment has become increasingly widespread to the benefit of generalizing results, understanding the physical phenomena, disciplining the investigators, and promoting international cross-fertilization in the science of ships.

k. The scope of model investigations is being enlarged

tremendously from traditional model tests in a straight line to experiments in 2 and 3 dimensions and up to 6 degrees of freedom.

l. The nature of model techniques is likewise expanding rapidly from steady state observations to dynamic and transient conditions.

m. In many countries, inadequate attention is being given to observing flow conditions around models, appendages, and propulsion devices. One look can often reveal more than thousands of routine measurements. A new classic (1) should do much to increase consciousness of the importance of observing and studying flow.

n. The growing need for research in hydroelasticity, as applied to ship design, is beginning to be more widely recognized.

o. Several areas have been researched beyond the point of diminishing returns and could well be dropped from international emphasis.

p. The Union of Soviet Socialist Republics contributed significantly to the conferences and unquestionably is one of the leading countries in hydrodynamic research.

q. Participation in and financial contributions to ship model research abroad by private ship design and shipbuilding interests exceeds greatly support from these sources within the United States. Here the major burden by far is carried by the United States Navy.

r. Because of heavy private support of ship model research abroad, many areas of merchant ship investigation are stimulated much more strongly than in the United States.

s. The United States is still among the leaders in ship model research but will have to hump vigorously to retain this position.

II. INTERNATIONAL AGREEMENTS

The International Towing Tank Conference deals solely with professional tankery; that is, the science of predicting full scale ship behavior from model experiments. The following digest has been prepared to summarize the principal agreements reached and objectives set at the 1957 Conference:

a. All tank establishments will submit detailed descriptions of their present methods for carrying out and analyzing propulsion experiments, for open water propeller experiments, for estimating ship performance, and for comparing trial results with model predictions. From study of the many different procedures, standard methods will be recommended for general international use.

b. In the field of propulsion, international study will be pursued on propeller scale effect including turbulence stimulation, on methods of determining full scale wake factors, on propeller-rudder interaction, on thrust deduction theory and experiment, and on fluctuations of torque and thrust.

c. As the Conference favored a model-ship correlation formula close to the 1947 American Towing Tank Conference (Schoenherr) line above a Reynolds Number of 10^7 but steeper at lower R's, the following was adopted:

$$C_F = \frac{0.075}{\left(\log_{10} \frac{R}{100}\right)^2}$$

to be known as the "ITTC 1957 Model-Ship Correlation Line."

d. In the field of frictional resistance, international study will be pursued on roughness allowances, on effect of form on frictional resistance, on improved techniques in turbulence stimulation, and on tank boundary interference.

e. Propeller work will include systematic investigations in one or two tunnels on the effect of air content on cavitation phenomena, the collection of data to enable comparison between cavitation tunnel tests and full scale results, fundamental work on slotted wall test sections for propeller tests, experiments in different tanks and tunnels on standard propellers, effect of unequal flow distribution, closer coordination between open water and tunnel results, and the relevant properties of water including the effect of nuclei and entrained air.

f. In the seagoing qualities of ships, the proposed studies include the collection of full scale sea and ship performance data to make model tests meaningful, the development of non-dimensional methods of presenting data for head and oblique seas, comparative tests in waves for two geometrically similar models properly scaled, interchange of information on test techniques in waves, and the development of theoretical methods for design and evaluation of experiments.

g. Preparation of standard values for kinematic viscosity of fresh and sea water.

III. THE PEOPLE

The committees appointed by the 1957 International Towing Tank Conference to serve and to implement international agreements until the 1960 conference in Paris are:

Standing Committee

General R. Brard ..... France
Captain M. L. Acevedo ..... Spain
Professor W. P. A. van Lammeren ..... Netherlands
Professor J. K. Lunde ..... Norway
Captain H. E. Saunders ..... United States
Dr. F. H. Todd ..... Great Britain

Scale Effects On Propellers and Self-Propulsion Factors

Dr. Hans Edstrand ..... Sweden
Dr. Fritz Gutsche ..... Germany
Mr. J. B. Hadler ..... United States
Mr. J. Krivtzoff ..... U.S.S.R.
Mr. L. P. Maillard ..... France
Mr. R. N. Newton ..... Great Britain
Professor E. V. Telfer ..... Great Britain

Skin Friction and Turbulence Stimulation

Professor C. W. Prohaska ..... Denmark
Captain M. L. Acevedo ..... Spain
Dr. George Hughes ..... Great Britain
Dr. M. Kinoshita ..... Japan
Dr. L. Landweber ..... United States
Mr. A. J. W. Lap ..... Netherlands
Dr. Karl Wieghardt ..... Germany

Comparative Cavitation Tests of Propellers

Dr. H. W. Lerbs ..... Germany

Professor L. C. Burrill ..... Great Britain
Dr. J. D. van Manen ..... Netherlands
Mr. L. Mazarredo ..... Spain
Ch. Eng. L. Pehrsson ..... Sweden
Mr. A. Silverleaf ..... Great Britain
Mr. A. J. Tachmindji ..... United States

Seagoing Qualities of Ships

Dr. M. St. Denis ..... United States
Dr. O. Grim ..... Germany
Dr. H. Kato ..... Japan
Professor E. V. Lewis ..... United States
Mr. E. C. Tupper ..... Great Britain
Mr. G. Vossers ..... Netherlands
Mr. A. I. Voznessensky ..... U.S.S.R.

Presentation of Resistance and Propulsion Data

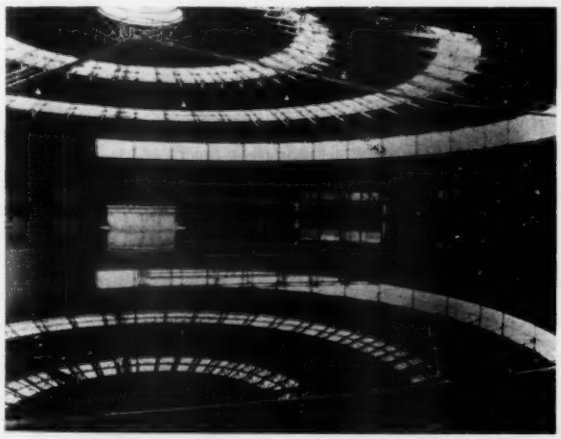
Captain H. E. Saunders ..... United States
Dr. E. Castagneto ..... Italy
Mr. J. M. Ferguson ..... Great Britain
Mr. H. Lackenby ..... Great Britain
Mr. S. D. Mathews ..... Canada
Dr. H. F. Nordstrom ..... Sweden
Professor S. Silovic ..... Yugoslavia
Dr. H. Amtsberg ..... Germany

IV. PHYSICAL GROWTH

Although laboratory facilities are forever secondary to laboratory people, their growth has interest and significance in that (a) they embody the ideas of their creators, and (b) they represent positive financial commitments of the sponsoring countries to new and extended fields of ship model research. Hence the remainder and majority of this paper are devoted to description of these more factual international aspects.

ROTATING ARM BASINS

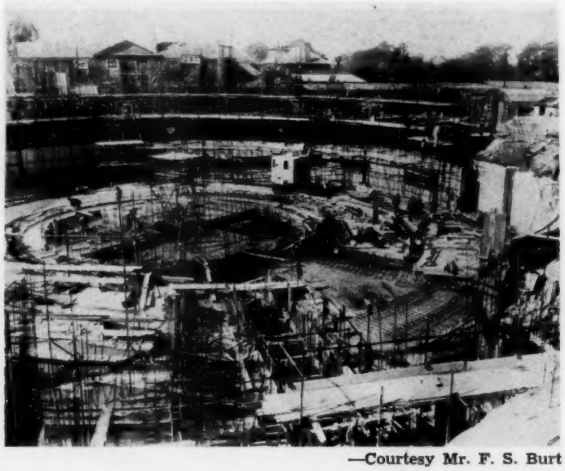
A striking development of the current decade is the increasing ability to predict the course keeping qualities of ships and submarines, and their paths under the influence of control surfaces. The prediction technique depends presently upon the experimental determination of hydrodynamic coefficients for the body and its appendages, the substitution of these coefficients in the differential equations of motion, and the calculation manually or by analog computer of the flight path under different conditions. The rotary coefficients of motion are best obtained by towing the body in a circular path and measuring the forces thereon.



—Courtesy of the Director

Figure 1. The Rotating Arm Facility at the Bassin d'Essais Des Carenes in Paris. The end of the arm to the left in the photograph is pivoted on an island in the center of the basin, and the right end is driven around a peripheral track by the two motors whose hoods can be seen. The overhead catwalks are used for photography.

The first large rotating arm basin designed for the purpose was completed by the French at the Bassin d' Essais des Carenes in Paris in 1945 (2). This circular model basin, 213 feet in diameter and 16 feet deep, has an arm pivoted in the center and rolling at its outer end on a circular track, Figure 1. Two 25 HP motors with Ward-Leonard control drive the outer end of the arm through two rubber-tired wheels at speeds up to 19 knots. The new large towing basin in Paris completing in 1958 connects with the rotating arm basin to permit radio-controlled turning models a long straight accelerating run before the rudder is laid over.



—Courtesy Mr. F. S. Burt

Figure 2. Rotating Beam Basin Under Construction at the Admiralty Research Laboratory. All concrete is heavily reinforced, particularly the footing for the 16-foot diameter concrete base required to support the kingpost within 8 seconds of arc to the vertical.

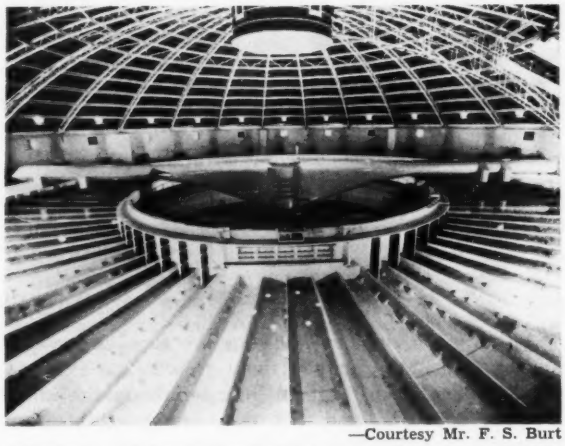
A rotating arm was installed in the 75-foot square, 4.5-foot deep, maneuvering basin at the Stevens Institute of Technology near the close of World War II, and much pioneering work on the steering and turning of ship models has been done in this facility.

At the Admiralty Research Laboratory, Tedding-

ton, England, a rotating-beam channel (3) has recently been completed and embodies spectacular engineering performance. The annular channel, shown under construction in Figure 2, has an outside diameter of 136 feet, a depth of 15 feet, and is 34 feet wide. Spoilers and beaches inhibit currents, wave reflections, and hydraulic resonance. The rotating beam, Figure 3, is supported and driven at the center only. The beam moves at a maximum peripheral speed of 90 knots at the 50-foot radius, while supporting a model weighing 3,000 pounds and creating a drag force of 4,000 pounds applied 5 feet below the water surface. Centrifugal acceleration is 14g. Underwater, large picture windows, which if broken will be closed automatically by steel shutters, provide comfortable observation stations.

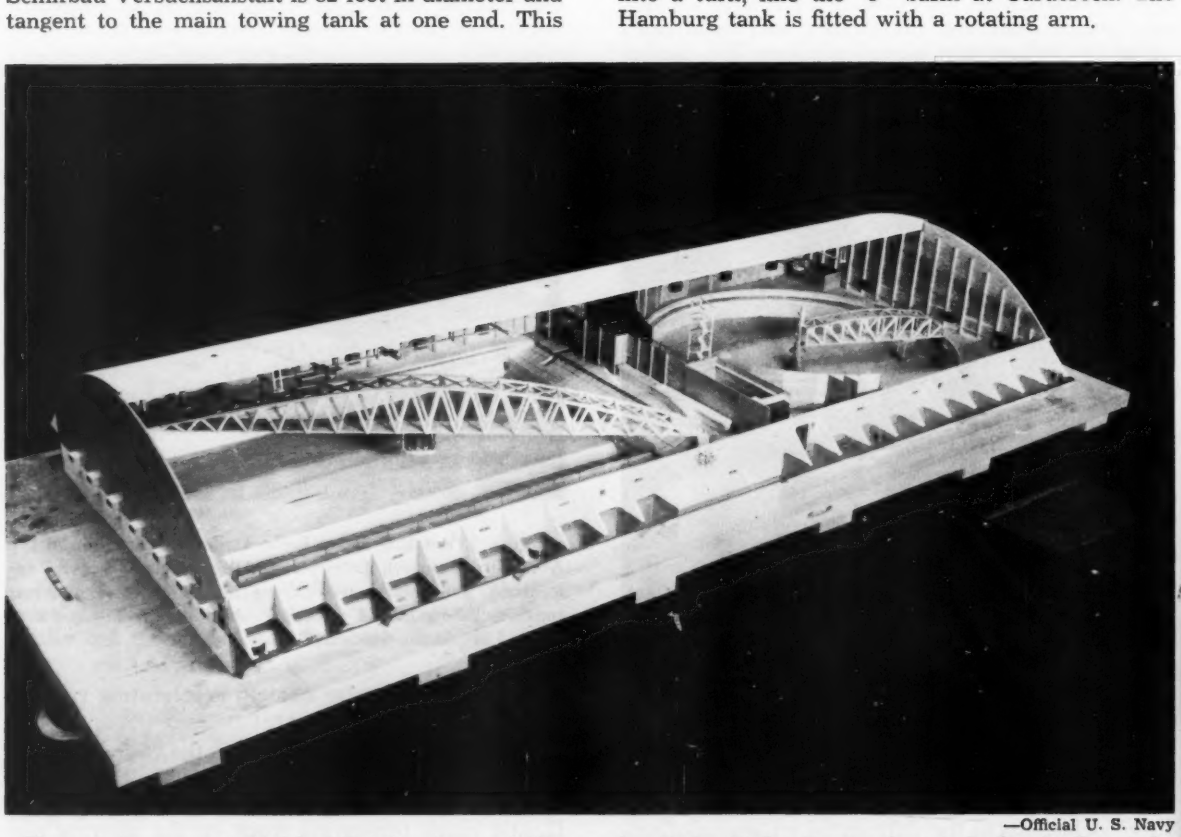
At the Admiralty Experiment Works, Haslar, England, which serves the same ship design needs for the British Navy as the David Taylor Model Basin does for the U. S. Navy, extensive construction is underway for new ship model research. A rotary arm facility will form a part of a large maneuvering and seakeeping basin (4) now building.

The maneuvering basin at the Hamburgische Schiffbau Versuchsanstalt is 82 feet in diameter and tangent to the main towing tank at one end. This arrangement provides a straight accelerating run under the towing carriage before the model goes into a turn, like the "J" basin at Carderock. The Hamburg tank is fitted with a rotating arm.



—Courtesy Mr. F. S. Burt

Figure 3. Rotating Beam Basin Completed at the Admiralty Research Laboratory. Through the highly-filtered water can be seen the swirl plates radially in the basin floor and the viewing ports in the island. The 122-foot symmetrical beam weighing 60 tons rotates at speeds up to 1 revolution every 2 seconds.



—Official U. S. Navy

Figure 4. Arrangement Model of Rotating Arm and Maneuvering Basins Under Construction at Carderock. Except for housing under the same roof, with an open span of 274 feet by 692 feet, the basins are physically and functionally separate with the maneuvering basin to the left in the photograph and the rotating arm basin to the right.

The rotating arm facility under construction at the David Taylor Model Basin will be housed with, but entirely separate from, the new maneuvering basin, Figure 4. To permit using the same standard 20-foot model throughout all the various tests at Carderock, the circular basin will be 260 feet in diameter with a water depth of 20 feet (5). The 38,000-pound, tubular aluminum, rotating arm will be driven by two 250 HP motors through 30-inch steel wheels rolling on a peripheral steel track. The arm is designed to accelerate from rest to 30 knots at the 120-foot radius in ½ revolution to permit readings on surface ship models before they overtake their surface wave system. Maximum arm speed at the 120-foot radius will be 50 knots. A 20-foot submarine weighing 2600 pounds held by struts 10 feet below the water surface can attain a 12 knot arm speed within one-half a turn for any radius between 48 and 120 feet. On the underside of the rotating arm, there will be a small carriage which can be remotely controlled to position the model in radius, roll, pitch and yaw.

SEAKEEPING AND MANEUVERING BASINS

Worldwide scientific attention is being brought to focus on the seakeeping qualities of surface ships. At the Symposium in the Netherlands, 45 important technical papers covering every aspect of wavegoing were presented; among the authors were representatives of the National Institute of Oceanography in Great Britain, University of Tokyo, A. N. Kryloff Shipbuilding Research Institute of the U.S.S.R., Stevens Institute of Technology, University of California, Hamburgische Schiffbau Versuchsanstalt, Transportation Technical Research Institute of Japan, Massachusetts Institute of Technology, New York University, Technical University Berlin-Charlottenburg, Iowa Institute of Hydraulic Research, King's College, Netherlands Meteorological Institute, Royal Netherlands Navy, University of Trieste, National Physical Laboratory, Delft Shipbuilding Laboratory, National Research Council of Canada, Netherlands Ship Model Basin, Stanford University, Leningrad Shipbuilding Institute, and David Taylor Model Basin (6).

—Courtesy Professor W. P. A. van Lammeren

Figure 5. First Seakeeping Basin, created by the Netherlands Ship Model Basin. The angles and complexity of the waves are varied by snake-type generators along the left side in the photograph and at the far end. The towing carriage runs in a fixed direction on the rails which can be seen through the right hand row of columns.

Ship model research in seakeeping calls for controlled tests not only in regular head and following waves as has been the practice, but also in irregular and short-crested waves at various angles of encounter. Consequently a new type of model basin is needed.

The Seakeeping Laboratory of the Netherlands Ship Model Basin (7), completed in May 1956, is the first facility in operation for ship model tests in a wide spectrum of simulated sea conditions. In the snake type wave generators, elements 2 feet wide can be phased to send out wave trains in a wide choice of directions and crest shapes, Figure 5. Then, with such wavemakers on two adjacent sides of the basin, patterns of irregular short-crested waves can be obtained. Consequently, the towing carriage need run only in a fixed direction. The 9-ton carriage is driven up to 10 knots by 3.7 HP motors to each of four 39-inch wheels on rails supported by two rows of pillars for the length of the 328-foot basin. The basin is 80 feet wide and 8 feet deep. The models, 10 to 13 feet in length, are self-propelled and fitted with automatic steering gear.

The Stevens Institute of Technology has put into operation a plunger type of wavemaker along one 75-foot side of their square maneuvering basin (8). Long-crested regular and irregular waves will be generated primarily, with provision for short-crested seas by temporary local extensions of the wavemaker face. A bridge, which can be positioned across the basin at various angles to the wave system, will carry on the underside a light towing carriage. Models approximately 4 feet long are contemplated.

At Feltham 5 miles from Teddington, the National Physical Laboratory is building a completely new Ship Hydrodynamics Laboratory, Figure 6, with all of the balanced components and facilities for the operation and support of modern ship model research (9). Included in the construction is a maneuvering and seakeeping basin, 100 feet square by 8 feet deep, Figure 7. Along one wall is being provided a continuous plunger type wavemaker, with a deep hollow-faced wedge, to generate waves up to 15 feet long and 9 inches high. Later an articulated plunger-type wavemaker will be added along an adjacent wall to superimpose waves at different angles on the main pattern. Free-running, radio-controlled models in the order of 10 feet long are contemplated for both maneuvering and wavegoing tests.

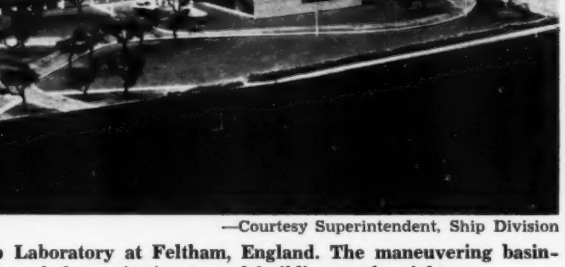
Announcement was made at the 1957 internation-

—Courtesy Superintendent, Ship Division

Figure 6. Model of Main Building Group of the New NPL Ship Laboratory at Feltham, England. The maneuvering basin-shop group is to the left, the new deep water basin in the center, and the cavitation tunnel building to the right.

—Courtesy Superintendent, Ship Division

Figure 7. Maneuvering Basin Under Construction at Feltham. The wax model storage and transfer tank in the background will connect the model shops and the main towing basin.



—Official U. S. Navy

Figure 8. Construction of DTMB Seakeeping and Maneuvering Basin. The seakeeping basin will be at the far end; holes for the pneumatic wavemaker ducts can be seen near the tops of the basin walls. The rotating arm basin will be at the near end; the center support can be seen to the right in the photograph.

al conferences that the Admiralty Experiment Works at Haslar has under construction a large seakeeping and maneuvering basin. Principal dimensions will be a length of 400 feet, a width of 200 feet, and a water depth of 18 feet. Plunger type wavemakers will be installed at one end and along one-half of the long side of the basin.

In Canada, the National Research Council at its model basin at Ottawa is constructing a large maneuvering basin 400 feet long by 200 feet wide by 10 feet deep. Wavemakers may be added in the future.

At the Technical Research Institute in Tokyo, self-propelled models 26 to 28 feet long in which 1 or 2 men ride are tested for maneuvering qualities. The basin is shaped like a right-angled triangle, over 600 feet on one leg and 440 feet on the other leg, with a depth of 20 feet. A 60-foot tower in the center is used to photograph the model paths.

The U.S.S.R. delegation to the International Towing Tank Conference announced the construction of a tremendous new open maneuvering and seakeeping basin (10). This facility will have a width

of 230 feet, a length of 558 feet, and a depth of 18 feet. Plunger type wavemakers for this basin are under construction and nearing completion.

At the David Taylor Model Basin, as at the Admiralty Experiment Works, the physical dimensions of the maneuvering and seakeeping basin were selected so that models of the standard length could be tested. The rectangular basin therefore has a length of 360 feet, width of 240 feet, and depth of 20 feet over most of the floor area, Figure 8. Parallel to a long wall, a 50-foot wide trench is being provided to have a water depth of 35 feet for testing free-running, submarine models and for observing them through windows in the wall. The wavemakers will be pneumatic, run the length of two adjacent walls, generate waves up to 40 feet long and 2 feet high, and absorb about 2500 HP at maximum load. Considerable flexibility is being built into operation and control of the wavemakers to permit creation of a wide range of controlled sea conditions. The highly effective grid type beach design is the result of exhaustive experiments at the St. Anthony Falls Hydraulic Laboratory. Spanning the length of the basin, and movable between runs to angles from 0 to 45 degrees to the basin axes, is a 376-foot bridge weighing about 230 tons which carries an aluminum towing carriage on its underside. The carriage will have a maximum speed of 15 knots, will accelerate up to 0.4g by the tractive effort of rubber tires driven by two 30 HP motors, and carry operating personnel, controls, and instrumentation for constrained and free-running models.

In addition to specialized seakeeping model basins, many laboratories are providing or improving wave making and absorbing equipment in their main basins. These will be described under the section on Towing Tanks.

The validity of seakeeping predictions from ship model tests must first be established by correlation with precise observations of full scale ship behavior under known sea conditions. In preparation for such correlations, a number of seakeeping trials are in various stages of completion.

The Royal Netherlands Navy and the David Taylor Model Basin, assisted by the Institute of Applied Physical Research in Delft and the University of Ghent, have conducted extensive seaworthiness trials on the destroyers HNMS *Friesland, Zeeland,* and *Everstsen* (6). Simultaneous measurements were made of roll and pitch angles; transverse, longitudinal and vertical accelerations, hull stresses in deck and keel, and bottom pressure at 8 stations along the length.

The U. S. Maritime Commission, Bureau of Ships, and David Taylor Model Basin are conducting seakeeping trials on two 6,000 HP Liberty ships, one of which has been lengthened 25 feet and the forebody considerably fined. Not only are the ship motions and accelerations being measured concurrently and comprehensively, but also the sea state with equipment developed by the British Institute of Oceanography at Wormley. These shipborne meters correct static wave pressure readings for roll of ship and for heave by double integration of accelerometer signals.

The Swedish Shipbuilding Research Association and the David Taylor Model Basin are collaborating on full scale strain and motion observations in the high-speed cargo ship MS *Canada.* Several round trips have been made from Sweden to Vancouver, and joint analysis of the observations is being undertaken. Shipbuilding Research Associations in Great Britain and a number of other countries are engaged in explorations of this kind.

The U.S.S.R. has developed considerable instrumentation for full scale trials, including gyro-recorders for ship motions, pressure gages for hydrodynamic loadings, and strain gages for measurement of hull stresses (10). During full scale trials under a variety of sea conditions, waves are measured by wave pole, by buoy and by stereophotography. The buoys are equipped with radio telemetering apparatus for transmitting information to shipboard on wave heights and periods.

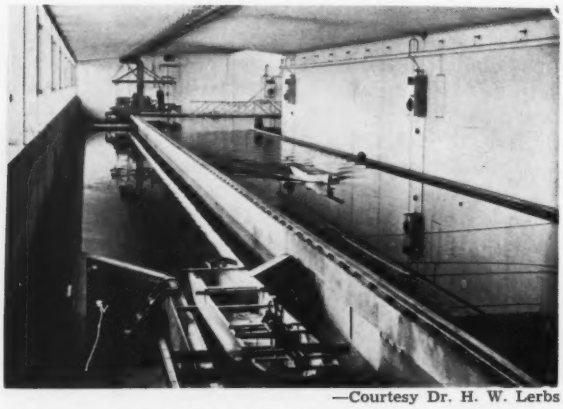
The subject of Dynamic Forces and Moments in a Seaway was included in the formal agenda of the International Towing Tank Conference for the first time in 1957. This step recognizes that study of elastic responses in a ship, such as strains, accelerations, pressures, and vibrations, depends basically on increasing knowledge of the exciting hydrodynamic forces. Conversely, these forces can be markedly effected by the elastic character of the interface.

Under the sponsorship of the Bureau of Ships and technical cognizance of the David Taylor Model Basin, instrumentation has been devised and tests run by the Stevens Institute of Technology on a destroyer model in waves. Not only the bending moment but also the shear amidships was measured, and it has been possible to reproduce in the model the 2-noded natural hull frequency corresponding to this vertical vibration characteristic in the ship (10). This pioneering technique was initially triggered by the Society of Naval Architects and Marine Engineers.

Loading studies on ship models in waves, undertaken for the first time in Japan, are now also done at the Massachusetts Institute of Technology, Vickers-Armstrong in St. Albans, and others. Delft Technical University uses a plastic model, rather than a split model, and finds it convenient for observing hull strains in any direction. The Kryloff Shipbuilding Research Institute at Leningrad studies forces on a ship model in a seaway by measuring pressures on the hull, by strains produced in a split model, and by measuring accelerations.

TOWING TANKS

The Director of the Canal de Experiencias Hidrodinamicas at El Pardo was Chairman of the Stand-



—Courtesy Dr. H. W. Lerbs

Figure 9. Hamburg Model Basin Complex of Facilities for Medium Sized Models. From the left can be seen the combined shallow water basin and flow channel, the monorail towing carriage which serves the basins on each side, the maneuvering basin with rotating arm projecting, and the main basin.

ing Committee of the International Towing Tank Conference and host to the Eighth Meeting held in Madrid. Through his most thorough and hospitable arrangements, 96 model basin directors and delegates from 21 nations met in valuable technical sessions covering many aspects of tankery. The reports, discussions, decisions and recommendations are being distributed by the Spanish Organizing Committee. During the Conference, opportunity was provided to visit and to see in operation the complete facilities at El Pardo. The main towing tank was lengthened 360 feet in 1946 to a new length of 1050 feet. The original cross-section, 41 feet wide by 21 feet deep, was retained throughout.

One of the most remarkable laboratory advances of this decade is occurring at the Hamburgische Schiffbau Versuchsanstalt in Western Germany. With the pre-War basins in ruins, a completely fresh start has been made in another section of the city. Since opening in 1950, over 820 ship models and 560 propeller models have been made and tested.

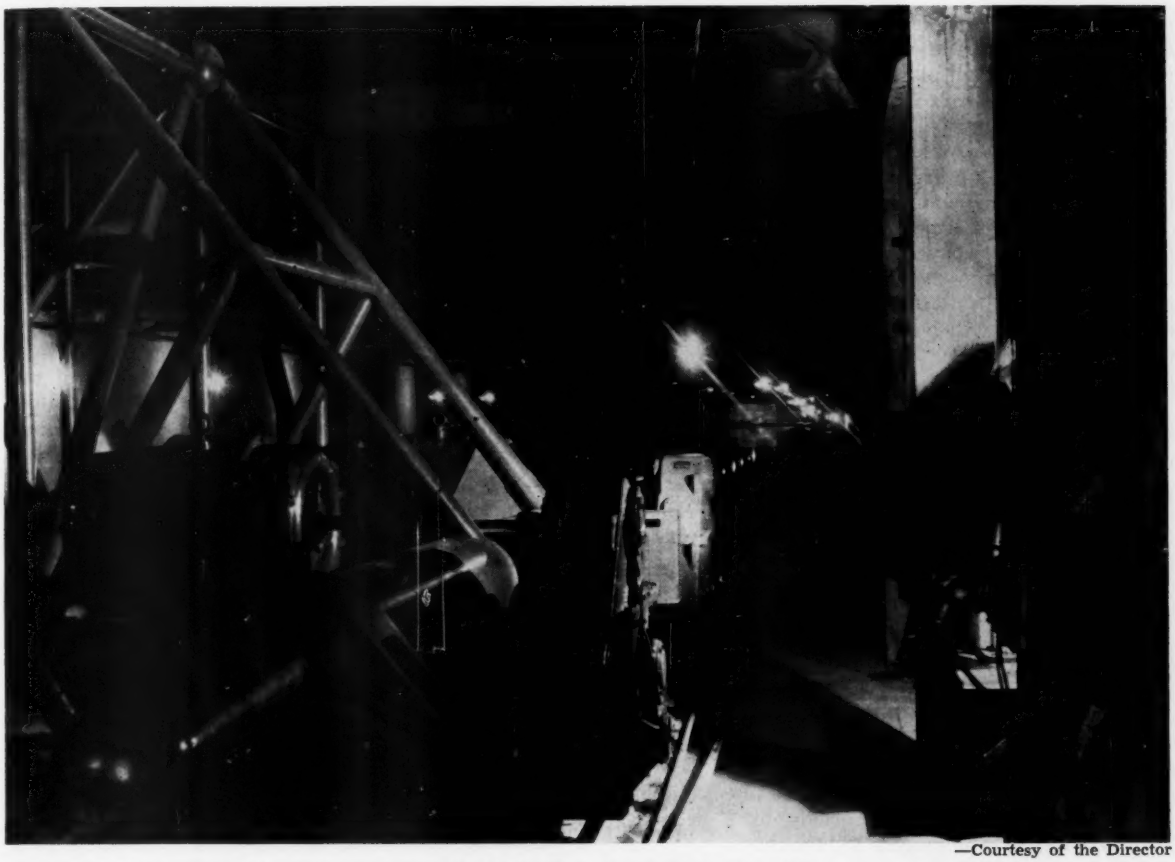
Initially at Hamburg, a compact complex of flexible medium-sized facilities has been built, Figure 9. The main towing tank is 260 feet long, 16 feet wide and 10 feet deep for testing models about 15 feet long. When the portable plunger type wave generator is installed in the fitting dock end of the main basin, the water level is dropped below the fixed side beaches and wave quashing screens are lowered into the water between runs to reduce the waiting interval. The maneuvering basin is at the opposite end of the main tank. Unique among model basins, as far as known, is the monorail design of towing carriage at Hamburg. On the upper rail, supported by the reinforced concrete roof, run only carriage guide wheels. The lower rail carries guiding, weight, and tractive forces. Generators on the carriage supply the two main driving motors as well as the model under test. Maximum carriage speed is 7 knots; an independent wire towing arrangement is also provided over this basin for tests up to 12 knots. The monorail carriage travels between the shallow water basin and the main basin, overhanging both. Hence unobstructed views and photographs of the models under test can be obtained opposite the towing carriage.

New large facilities are under construction at Hamburg. The model basin, Figure 10, was filled for the first time in March 1956, and alignment of the rails is well advanced. The basin cross-section of 59 feet by 20 feet will provide an exceptionally large hydraulic radius. The present length of 656 feet is extensible to 1480 feet if required in the future. Rail laying is well advanced. The new towing carriage will be a massive precision instrument of highly original design. Its anticipated structural weight is 15 tons, total weight 26 tons. Four large wheels over 4 feet in diameter, each motor driven through gears, will propel the carriage at speeds up to 20 knots. Track brakes will grip the rail head for emergency stopping at any point, as at Carderock. Within the large rectangular bay of the main towing carriage, a secondary carriage will run athwartships, making possible in effect concurrent motion in both the X and Y directions. Thus it will be possible to execute zigzag maneuvers, and to run a model with waves on the bow and quarter as well as dead ahead and astern. The underside of the carriage is well elevated above the water surface. A plunger type wavemaker is planned. These fine new facilities at the Hamburgische Schiffbau Versuchsantalt are expected to commence operation by late Spring 1958.

At the Bassin d'Essais des Carenes in Paris (11), an equally impressive new model basin and towing carriage are in a comparable stage of construction, Figure 11. This large basin has a cross-section 40 feet wide by 15 feet deep, and a length on the water

—Courtesy Dr. H. W. Lerbs

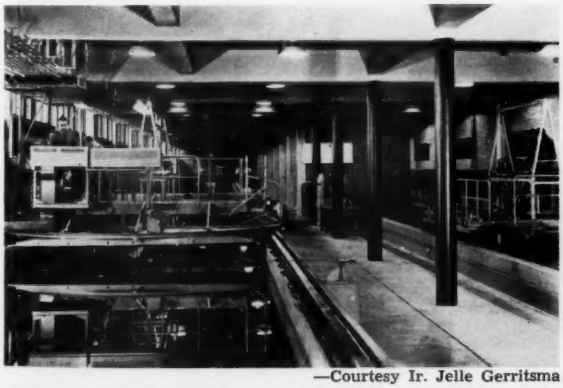
Figure 10. Widest Model Basin Spanned by a Towing Carriage, nearing Completion at the Hamburgische Schiffbau Versuchsanstalt. Above the fitting basin in the foreground can be seen the truss members of the new towing carriage and, at the extreme left and right, the large carriage drive wheels.



—Courtesy of the Director

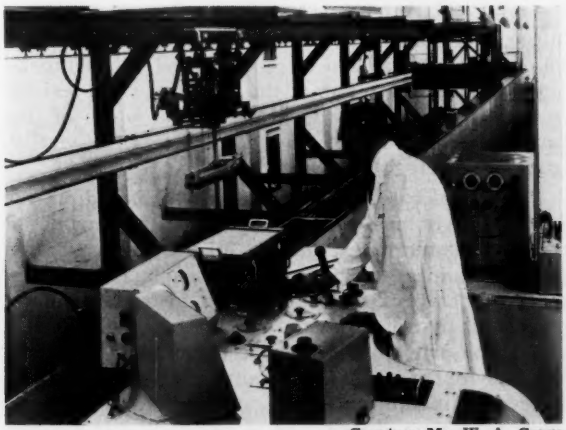
Figure 11. New Deep Water Basin and Carriage at the Pari Model Basin. Two of the four carriage driving units and a set of guide wheels can be seen. The stiff tubular construction is particularly well designed.

of 722 feet. It connects through double watertight gates to the circular maneuvering basin so that approach runs can be obtained. The watertight gates also provide a drydock without disturbing operations in either basin. The tubular carriage structure, with as many as 10 members joined at a single sphere, will be one of the sturdiest and stiffest in existence, attributes which are extremely important



—Courtesy Ir. Jelle Gerritsma

Figure 12. New Facilities of the University of Technology at Delft. To the left is the main tank and towing carriage; to the right is the combined shallow water basin and flow channel, also equipped with a carriage.



—Courtesy Mr. W. A. Crago

Figure 13. New Tank and Monorail Carriage Opened at Saunders-Roe in 1956. All carriage operations are controlled from and readings are transmitted to the console in the foreground.

in these days of diverse unforseeable demands for surface and subsurface experiments. The carriage is trapezoidal in overall plan form, and all driving and guiding are done from the same heavy rail. Four drive motors will propel the carriage at a maximum speed of 20 knots. An open dynamometer bay will provide great flexibility and economy in carriage time by rigging instrumentation for a particular test on shore and then lifting the entire assembly into the dynamometer bay. Windows for underwater viewing are set into the basin walls. It is expected that this fine facility will be in operation before the end of 1958, and will be a highlight of the next International Towing Tank Conference being planned for Paris in 1960.

The fruitfulness of having a model basin as a part of a school of naval architecture has been widely recognized and utilized. In Holland, the teamwork is carried to 3-way collaboration between the Netherlands Ship Model Basin, the University of Technology at Delft, and the Shipbuilding Laboratory of that University. Excellent new facilities for instruction and research in naval architecture have recently been completed at Delft (12). The towing tank has a length of 316 feet, and a rectangular cross-section 14 by 8 feet. A pneumatic type of wave generator produces not only regular waves, but also can be externally programmed on a plug board, like some new types of console calculating machines, to produce a wide variety of irregular waves. Blower power up to 25 HP supplying air to the plenum dome will generate waves with periods to 2 seconds, lengths to 20 feet, and heights to 11 inches.

Delft's towing carriage, weighing 5 tons, is propelled at speeds up to 15 knots by four 5 KW motors driving each of four 23-inch wheels, Figure 12. Complete instrumentation for resistance, propulsion, open-water propeller, and wavegoing tests are carried, together with a wire-resistance type of wave height meter. When self-propelling in waves, a small light secondary carriage provides full freedom in surge, pitch and heave, and tests of a DTMB Series 60 model in a head sea were witnessed with admiration. On the return run of the carriage when testing in waves, a wide board extending the width of the tank is lowered onto the water surface, and literally irons out the residual waves.

The model basins at Saunders-Roe Limited on the Isle of Wight are engaged in a wide spectrum of scaled dynamic investigations, all the way from the hydrodynamics of ski-supported seaplanes and the ditching of every class of aircraft to tests of minesweepers, hydrofoil boats, and all types of surface craft. The original 618-foot basin completed in 1946 has a towing carriage that attains a speed of 35 knots. Forced rolling and fin stabilization tests were underway at the time of visit. The second tank was opened in June 1956 (13). Here, from the monorail carriage, 14 instantaneous observations can be transmitted through a looped multicore cable to the control console, Figure 13. A 10 HP winch drives the light carriage at speeds up to 30 knots. Tank dimensions are length 250 feet, width 12 feet, and depth 6 feet; the cross-section is rectangular. The new tank has been fitted with a wavemaker of the plunger type and tests of a high speed surface craft in waves were observed.

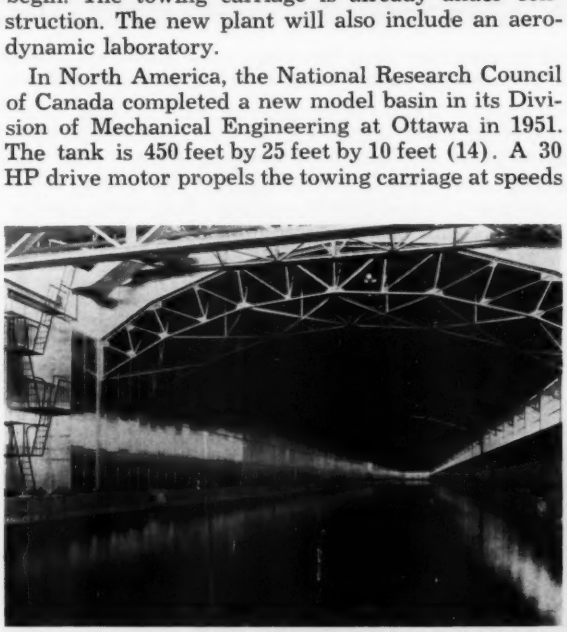
The Stevens Institute of Technology has been conducting sea-keeping experiments in their original towing tank, now fitted with a programmed generator for irregular waves.

In Berlin, a pneumatic type of wavemaker, that generates from the action of air suction as well as air pressure on the water surface in the dome, has now been put into operation.

At Feltham, the large new towing tank of the National Physical Laboratory had just been filled at the time of visit and track laying of all-welded rails was beginning. The generous cross-section of the tank, 48 feet by 25 feet, was determined by the desire to test larger self-propelled models, of the order of 24 feet long (9). Shop machinery is planned to process wax or wood models up to 40 feet in length. The towing carriage is designed for a 7-second steady run at 30 knots on a tank length of 1300 feet. The main tank, Figure 14, is almost entirely above ground level.

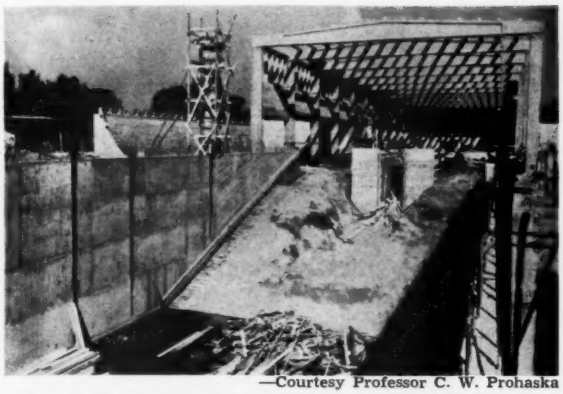
The Danish model basin is now under construction at Hjortekaer just north of Copenhagen, Figure 15. The main tank will have a length of 788 feet, a width of 39 feet and a depth of 18 feet. It will be filled in the late Spring of 1958 and track laying will begin. The towing carriage is already under construction. The new plant will also include an aerodynamic laboratory.

In North America, the National Research Council of Canada completed a new model basin in its Division of Mechanical Engineering at Ottawa in 1951. The tank is 450 feet by 25 feet by 10 feet (14). A 30 HP drive motor propels the towing carriage at speeds



—Courtesy Superintendent, Ship Division

Figure 14. Deepest Model Basin Spanned By a Towing Carriage, part of the New Feltham Complex of the National Physical Laboratory. Roof structure and side paneling are all of aluminum, giving a striking appearance to the interior of the long basin building.



—Courtesy Professor C. W. Prohaska

Figure 15. Fine New Facilities for Denmark are under Construction. View of eastern end and part of workshops.

up to 12 knots. MIT's 108-foot tank was put into operation in February 1951 (15). A programmed wave generator has now been added. The Robinson Model Basin at the Webb Institute of Naval Architecture was also completed in 1951. The U. S. Naval Academy at Annapolis now has a towing tank for the instruction of midshipmen (16). The tank is 52 feet by 6 feet by 4 feet, and is fitted with a gravity dynamometer and electronic speed calculator. The new tank of the University of California at Richmond became operational in the Fall of 1955. It is 200 by 8 by 6 feet, has both towing carriage and wave generator, and is being used for a variety of research including ship motions (17). Convair Division of General Dynamics at San Diego has a new 300-foot tank (18) as a part of its growing hydrodynamics laboratory. The planned facilities contemplate a second 300-foot tank in line with the first, and with a 100-foot square turning basin between them. The light monorail carriage can be operated up to 60 knots.

In 1951, an extension of 302 feet was made to the

—Courtesy of the Superintendent

Figure 16. Completely Modernized Original Tank at the Admiralty Experiment Works. The new carriage is driven by a synchronous motor at each corner.

35 by 18 foot main tank at the Netherlands Ship Model Basin, making the present length on the water 827 feet.

The original tank at the Admiralty Experiment Works was lengthened in 1957, together with new shops and drawing rooms in the extension (4). The tank is now 540 feet long by 20 feet wide by 9 feet deep. The wooden box girder towing carriage designed and built by William Froude has now been replaced by a completely new towing carriage, Figure 16. It is remarkable that the original Froude paddle type wavemaker was in such good condition that it was largely relocated at the extended end of the basin; waves up to 1 foot high and 20 feet long can be generated.

The new tank under construction in India is understood to be about 500 feet long, with a 12 by 7 foot cross-section and with a carriage speed up to 12 knots.

The Genoa tank, completed in 1947, is 158 feet long, 9 feet wide and 5 feet deep.

In late 1953, excavation started for the Istanbul Model Experimental Tank as a component of the Turkish Shipbuilding and Research Institute founded the same year (19). The towing tank is 245 feet long with a cross-section about 20 feet wide and 12 feet deep. The carriage, weighing approximately 9 tons, will be propelled up to 14 knots.

The Kryloff Shipbuilding Research Institute in Leningrad is unquestionably doing important scientific work in ship model research, as well as accomplishing an imposing amount of resistance and propulsion testing, in support of an extensive ship design and building program (20). The main tank there is so long, in the order of 2130 feet, that a number of readings at different speed settings can be obtained in one trip down the basin; this tank is 50 feet wide and 23 feet deep. The second tank is 490 feet by 20 feet by 13 feet. Both towing tanks at Leningrad have now been equipped with eccentric rotating drum type wavemakers. The tanks are apparently working a full 16 hours daily, and the large professional staff of perhaps 150 to 200 is very active. Russian representatives of the Kryloff Institute and of the Academy of Sciences in Moscow made significant technical contributions to both the Wageningen and Madrid conferences, and will in the future be represented on the technical committees of the International Towing Tank Conference.

In Brazil, the Naval Section of the Technical Research Institute has recently completed at Sao Paulo a ship model testing tank 197 feet long, 12 feet wide and 7.5 feet deep (21). The towing carriage for this new facility corresponds to those of larger basins, for it is designed to undertake propeller and self-propulsion as well as resistance tests, and to carry model testing personnel and the carriage operator. The rectangular 20 by 13 foot carriage weighing about 4 tons will have a speed range up to 10 knots.

The Mitsubishi model basins at Nagasaki, destroyed by the bomb, have now been completely

rebuilt and in full operation since August 1953 (22). Principal features are:

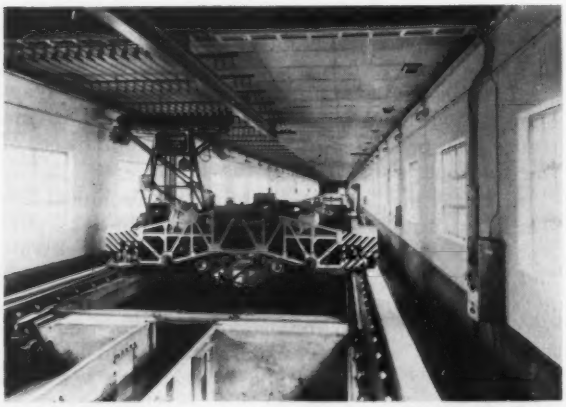
	Medium Tank	Large Tank
Length, feet	394	542
Width, feet	20	41
Depth, feet	12	21
Carriage drive, HP	12	100
Speed, max., knots	12	17
Models, max., feet	20	26

The two tanks are in tandem so that the large towing carriage can run the length of both tanks. A 30 HP wavemaker serves the large tank, Figure 17.

—Courtesy Hideo Fujita

Figure 17. The Mitsubishi Nagasaki Experimental Tank. Carriage and housing have been completely rebuilt; the flap of the new wavemaker can be seen in the foreground.

Extensive construction of new facilities is currently underway at the Meguro Model Basin of the Technical Research Institute in Tokyo. Completed in 1956, the small basin is 336 feet long by 11 feet wide and 7 feet deep, with a towing carriage driven up to 14 knots by four 7.5 HP motors, Figure 18. A pneumatic wavemaker for this basin was completed



—Courtesy M. Kanno

Figure 18. Small Tank at the Meguro Model Basin. Auxiliary pneumatic tires are used on concrete rails at both tank ends for high acceleration and deceleration.

in 1957. The large basin, 836 feet long with a cross-section 41 feet by 24 feet, is in the rail laying stage, Figure 19. The steel-tube all-welded towing carriage will be 52 feet long, will weigh 30 tons, and will be driven up to 32 knots by four 35 HP drive motors. A flap-type wavemaker, driven by a 100 HP motor and capable of generating waves over 3 feet high, has been installed in the large basin. Likewise building is a third basin 1140 feet long, 20 feet wide and 10 feet deep for still higher speed experiments.

At Kings' College in the University of Durham, a tank 130 feet long with a cross-section 12 by 5 feet was completed in July 1952 (23) for research and instruction in the Department of Naval Architecture, the first arrangement of this kind in England.

Since November 1951, full operations have been resumed in the Schiffbautechnishe Versuchsanstalt in Vienna, Figure 20. The basin is 590 feet by 33 feet by 16 feet, and the maximum carriage speed is 15 knots. This basin was heavily damaged in World War II.

At the Shipbuilding Research Institute in Zagreb, Yugoslavia, extensive construction is underway. Of the 4 new model basins now building, one will be a deep water basin about 905 feet long, 40 feet wide by 21 feet deep, and another a high speed basin almost 1000 feet long with a cross-section 16 by 10 feet and a carriage speed of 40 knots. Details will be announced at the time of opening, probably next year.

Considerable progress is being made in the development of techniques and instrumentation for resistance and propulsion experiments on submerged bodies in towing tanks, such as at the National Institute for the Study and Testing of Naval Architecture in Rome, Figure 21.

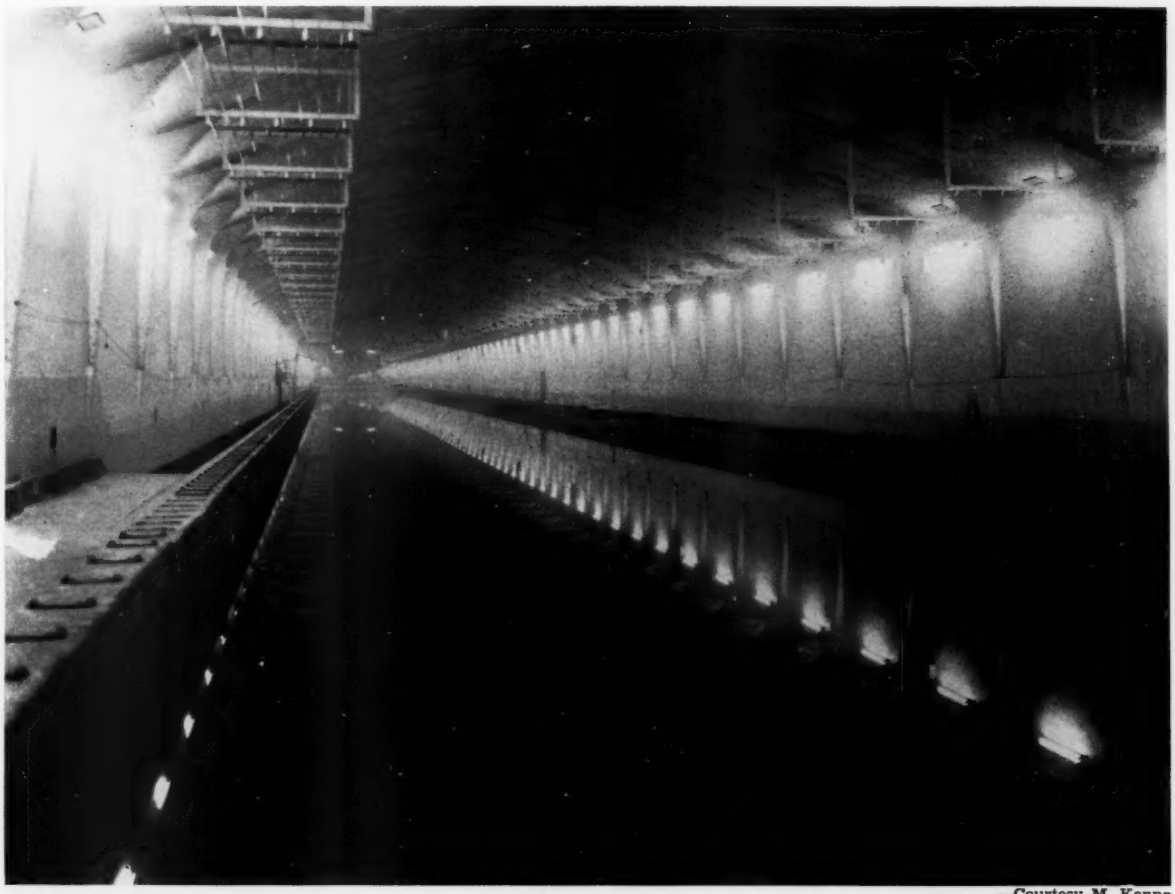
SHALLOW WATER BASINS AND FLOW CHANNELS

Channels at model basin establishments appear to be of three general varieties: (a) Shallow water basins in which the water is at rest and the towing carriage moves, (b) channels using either a carriage or flowing water or both, and (c) facilities designed for observing a stationary model in moving water.

The Paris Model Basin completed and put into operation in 1956 a separate shallow water basin with depth from 0 to 6.5 feet, utilizing the basin floor as was done at Carderock. This basin is 508 feet long and 30 feet wide, and will be used for maneuvering experiments in shallow water as well as resistance and propulsion, Figure 22. The towing carriage has a maximum speed of 10 knots. A gate type wavemaker was ready for installation when this tank was visited.

Another new addition to the Netherlands Ship Model Basin will be facilities for inland waterway tests and research (24). Construction is now well underway on this basin, Figure 23, which will be 712 feet long, 52 feet wide and 4 feet deep. Experimental work in this basin is already programmed over its first 5 years.

At Duisburg-Neudorf in Western Germany, special facilities were built about 1954 for the study of

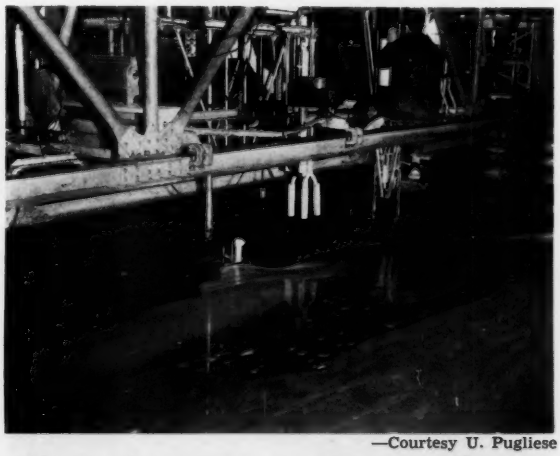


—Courtesy M. Kanno

Figure 19. New Large Meguro Tank of the Technical Research Institute, Japan. Completion of the rails, carriage and dynamometer is anticipated in 1958.

—Courtesy Dr. Leopold Kretschmer

Figure 20. War Damage Now Repaired at Original Gebers Tank In Vienna.



—Courtesy U. Pugliese

Figure 21. Towing Tests of a Submarine Model at the Rome Model Basin. Dynamometers have been built for self-propulsion experiments on submerged bodies.

—Courtesy of the Director

Figure 22. New Shallow Water Basin at Paris. A large towing carriage, complete with instrument room, is provided entirely for shallow water.

craft for inland waterways. The shallow water tank there is 130 feet long and 10 feet wide with a towing carriage. In addition, there is a large shallow tank which, after the second stage of construction, will be 360 feet long.

—Courtesy Dr. W. P. A. van Lammeren

Figure 23. The Netherlands Builds a Shallow Water Model Basin. A new maneuvering pond is in the background.

The Delft flow channel (12) has a length of 147 feet, a width of 9 feet, and a depth over an accurately-levelled bottom variable from 0 to 1.6 feet. A carriage over the channel will tow at speeds up to 5 knots in either direction. The water can be made to flow up to a velocity of 2 knots in the channel. The water circulates in a flat vertical loop, impelled by a 4-bladed 30 HP propeller.

The Hamburg combined shallow water basin and flow channel shares the use of the double-cantilevered towing carriage. The water depth is adjustable up to 2.2 feet in the channel of width 12 feet and length 262 feet. When at maximum section, a water flow of 2 knots can be obtained. Studies of the Baltic to North Sea Canal were underway at the time of visit to Hamburg. The flexibility to adjust the channel dimensions, water speed, and model speed in a facility of this kind is a material advantage in restricted waterway experiments.

The flow channel at Paris has large stilling reser-

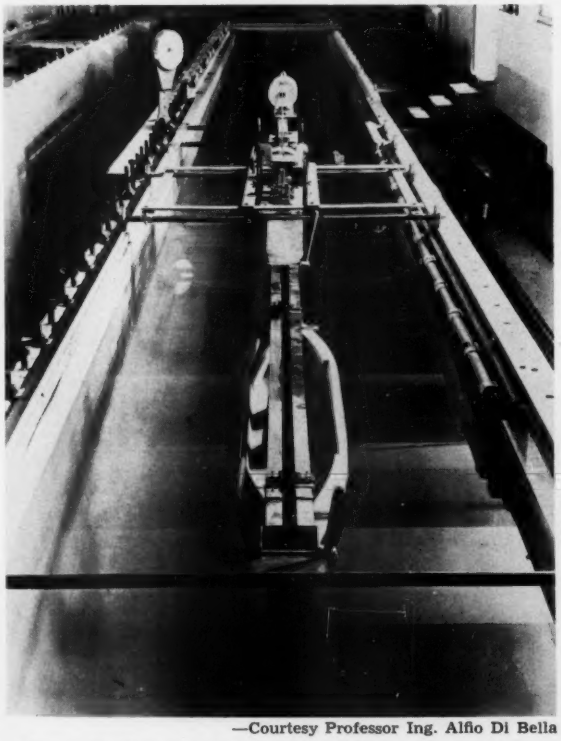
voirs both upstream and downstream of the channel to stabilize end conditions. Water is transferred between reservoirs by 4 hydraulic pumps, located low in the circuit. A water velocity of 12 knots can be obtained when the channel area is about 10 square feet. Windows in the channel sides are provided for observation.

The National Physical Laboratory has reached the final design stage on a circulating water channel with a test section about 6 feet wide and 4 feet deep, and with a maximum water speed a little below 4 knots (9). Initial model studies were made in the Cambridge University Engineering Laboratory under the sponsorship of the British Shipbuilding Research Association.

The Institute of Naval Architecture at the University of Genoa has a new circulating water channel now being calibrated, Figure 24.

In Japan, a new horizontal loop flow channel at the Technical Research Laboratory of the Hitachi Shipbuilding and Engineering company has a windowed cross-section 4 feet square. Calibrations are said to show velocity fluctuations less than $\pm$ 1 per cent up to 3.5 knots; the channel is already in use studying rudder action in a propeller race. It is understood that the flow circulating channel at the rebuilt Mitsubishi Experiment Tank, Nagasaki, has a measuring section 4 feet wide by 2.6 feet deep and a water speed of 4 knots.

A most unusual flow channel has recently been built at the DeVoorst Hydraulics Laboratory, located below sea level near Emmeloord on one of the remarkable polders of the Zuiderzee works. Here literally is a wind tunnel over a model basin. The basin is 328 feet long, with a width of 13 feet and depth of 2.5 feet. Air flows in a closed vertical loop at velocities over the water surface up to 40 knots. When this unique facility was observed in operation, the variation of wave height, length, and shape with fetch were strikingly apparent.



—Courtesy Professor Ing. Alfio Di Bella

Figure 24. New Circulating Water Channel Nearing Completion at the University of Genoa. Apparatus for graphically recording the model resistance appears on the centerline of the right leg of the channel.

CAVITATION TUNNELS

New variable pressure water tunnels are characterized by greater versatility, size, and attention to air content. The function of resorbers is to redissolve entrained air bubbles before they return to the test section. Following the lead of the Hydrodynamics Laboratory at the California Institute of Technology (25), many of the new cavitation tunnels are incorporating some form of resorber.

In the new water tunnel under construction at the National Physical Laboratory (9), an exceedingly deep resorber circuit of large volume is being incorporated in order to provide generous pressure and time encouraging air to redissolve. In fact the lower horizontal leg of the tunnel circuit is 180 feet below the test section and has a length of 87 feet. The steel tube below ground, from 10 to over 13 feet in diameter, is grouted into concrete rings.

Pressure in the 44-inch circular closed-throat test section of the NPL tunnel will be variable from near 0 up to 6 atmospheres absolute, and water velocity up to 30 knots driven by an 850 HP motor with a vertical shaft to the impeller in the downstream vertical leg. The working section will be at the

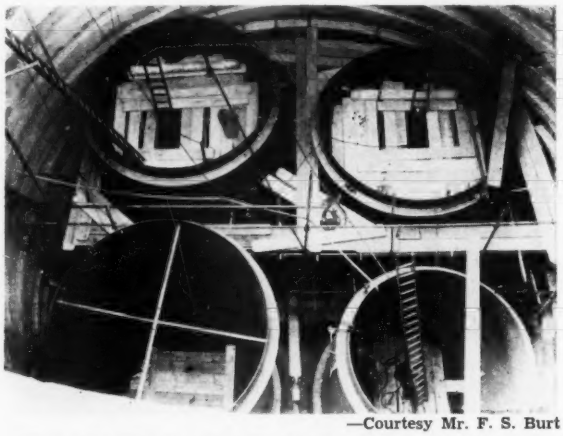
—Courtesy Superintendent, Ship Division

Figure 25. 44-Inch Water Tunnel Building Under Construction at Feltham for the NPL Ship Division. Laboratory offices will be in the foreground, the plant room in the back wing, and the cavitation tunnels between them athwartships.

ground level in a new water tunnel building, Figure 25.

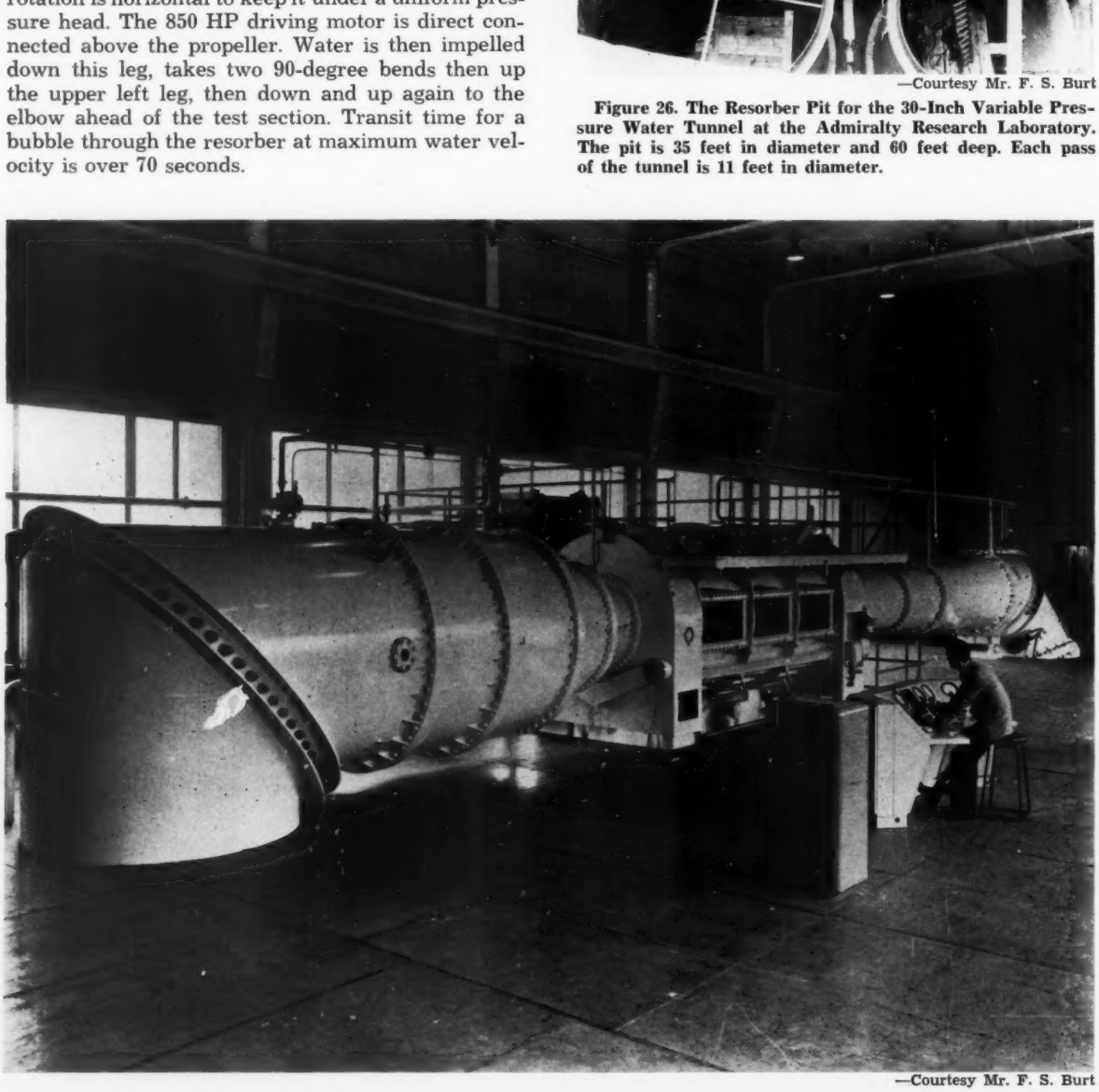
Provisions are being made at NPL for tests of 24-inch propellers in open water, using the same size model as planned for the new cavitation tunnel. An auxiliary carriage, to be towed by the existing carriage over the high speed basin at Teddington, has been built to carry the large propeller dynamometer.

The new 30-inch cavitation tunnel at the Admiralty Research Laboratory (3) has a 4-pass resorber. The lower left duct in the photograph, Figure 26, supports the variable pitch propeller whose plane of rotation is horizontal to keep it under a uniform pressure head. The 850 HP driving motor is direct connected above the propeller. Water is then impelled down this leg, takes two 90-degree bends then up the upper left leg, then down and up again to the elbow ahead of the test section. Transit time for a bubble through the resorber at maximum water velocity is over 70 seconds.



—Courtesy Mr. F. S. Burt

Figure 26. The Resorber Pit for the 30-Inch Variable Pressure Water Tunnel at the Admiralty Research Laboratory. The pit is 35 feet in diameter and 60 feet deep. Each pass of the tunnel is 11 feet in diameter.

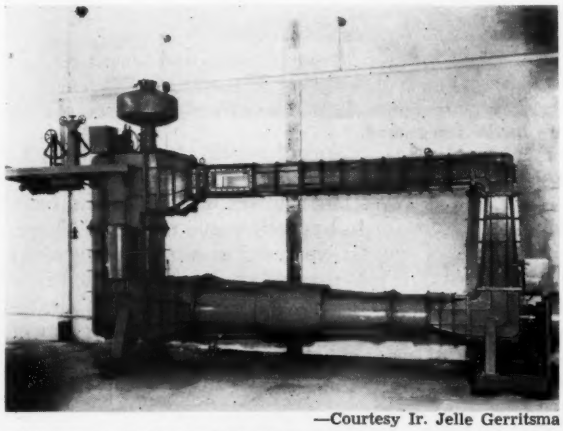


—Courtesy Mr. F. S. Burt

Figure 27. The Completed 30-Inch Water Tunnel at the Admiralty Research Laboratory. The flow direction is from the left in the photograph, past the 3 windows opposite the long working section, and then to an easy diffuser with a generous straight length before making the first 90-degree bend.

The Admiralty Research Laboratory tunnel has an exceptionally long test section, 15 feet equivalent to 6 times the diameter of the jet, Figure 27. Stability of flow, constancy of pressure, and greatly minimized wall effect are attained throughout the speed range up to 36 knots by a slotted wall working section. Slotted walls in water tunnels are new, and the Admiralty Research Laboratory was a prime developer of this arrangement. Slots were said to be really effective only when the test section is long. In this connection, the Superintendent pointed out that a working propeller is a long body and that a long test section is needed to treat it properly. Pressure in the test section is adjustable from about 0.1 to 3.0 atmosphere absolute. Principal instrumentation is by strain gages within the models under test.

The cavitation tunnel at the very modern Shipbuilding Laboratory of the Delft University of Technology (12) has a test section 11 inches square in which a water velocity up to 18 knots is obtained by a 20 HP impeller hydraulically varied up to 700 RPM, Figure 28. The propeller shaft is in the down-

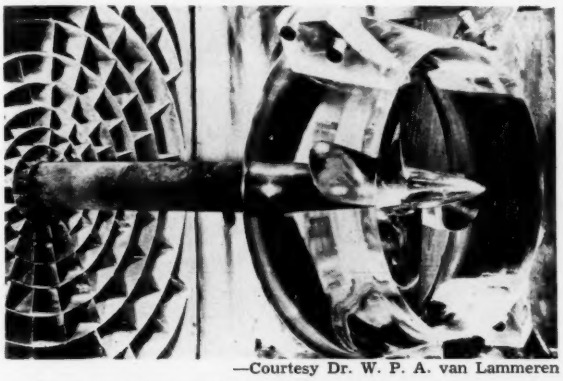


—Courtesy Ir. Jelle Gerritsma

Figure 28. Delft Variable Pressure Water Tunnel. Developmental work for the variable wake tunnel at Wageningen was accomplished here.

stream direction, as in the ship, and propeller model measurements are taken up to 3000 RPM and 4.3 HP. These conditions are obtained with the conventional guide vanes and honeycomb in the elbow ahead of the propeller position. The Delft tunnel was utilized by the Netherlands Ship Model Basin to develop a flow regulator to simulate circumferential as well as radial wake variations over a propeller disc. An alternate elbow ahead of the test section was divided essentially into 146 elements, the flow through each of which could be regulated. A rotating rake with 13 pitot tubes enabled a rapid velocity survey to check the desired velocity distribution. Another development at Delft is a new test section, about 6 inches wide, in which a 2-dimensional propeller profile can be moved transversely to simulate a propeller blade in circumferentially varying wake.

The variable wake cavitation tunnel at the Netherlands Ship Model Basin becomes another classic first for that ingenious laboratory (26). The test section is circular, 16 inches in diameter, with a slotted wall to reduce boundary effects, Figure 29. With



—Courtesy Dr. W. P. A. van Lammeren

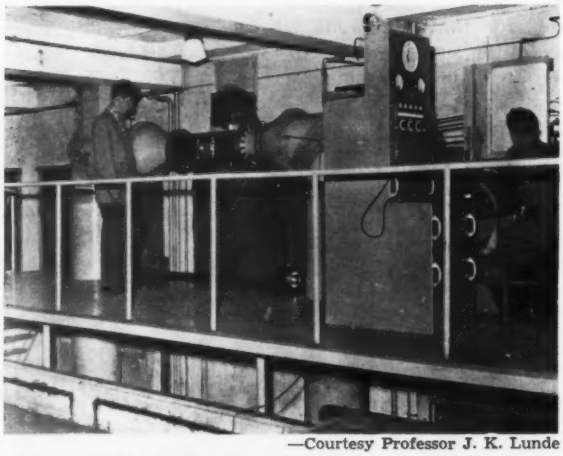
Figure 29. First Variable Wake Variable Pressure Water Tunnel, Developed by the Netherlands Ship Model Basin. Flow is individually controlled through each of the ducts to the left in the photograph; the propeller is being tested in a nozzle which has been made of plastic so the flow can be observed.

partly closed flow regulator, the minimum cavitation number is about 2, and the maximum water velocity about 12 knots.

The Paris cavitation tunnel, Figure 30, has a closed

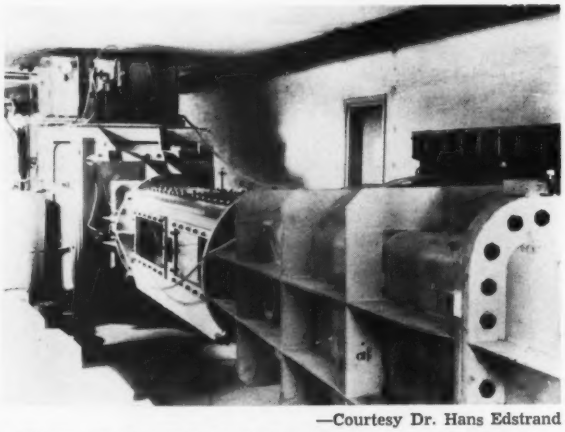
—Courtesy of the Director

Figure 30. Lower Loop of Cavitation Tunnel at the Paris Model Basin. The bellows filter vibrations that may arise from the impeller driven by the large motor in the foreground.



—Courtesy Professor J. K. Lunde

Figure 31. Norwegian Tunnel Model at Trondheim. In this arrangement, flow conditions are being studied in an exceptionally short diffuser section to the right of the flexiglass test section.



—Courtesy Dr. Hans Edstrand

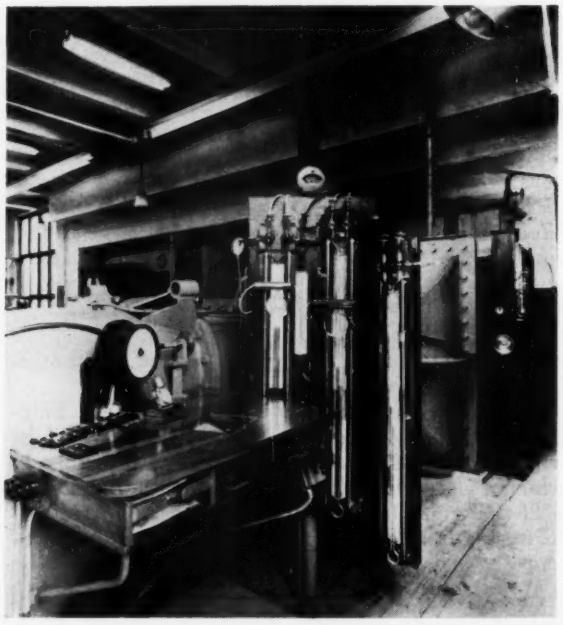
Figure 32. Swedish Cavitation Tunnel Recently Completed at Göteborg.

throat of clear plastic about 36 inches in diameter. A water velocity of 30 knots is attained in the test section of this tunnel.

The Admiralty Experiment Works has erected and housed a very large cavitation tunnel (4).

In Norway at the Trondheim Ship Model Tank, experiments are underway on a small tunnel to gain experience for a proposed large cavitation tunnel. The present facility, Figure 31, has a basic 8-inch diameter closed jet working section with a water speed of 20 knots, and two alternate slotted wall arrangements with maximum test speeds of 10 and 24 knots respectively.

The Swedish State Shipbuilding Experimental Tank at Gothenburg has recently added to its excellent facilities (27) a new variable pressure water tunnel, Figure 32. The Kristinehamn tunnel of KMW, Figure 33, continues its outstanding propeller research.



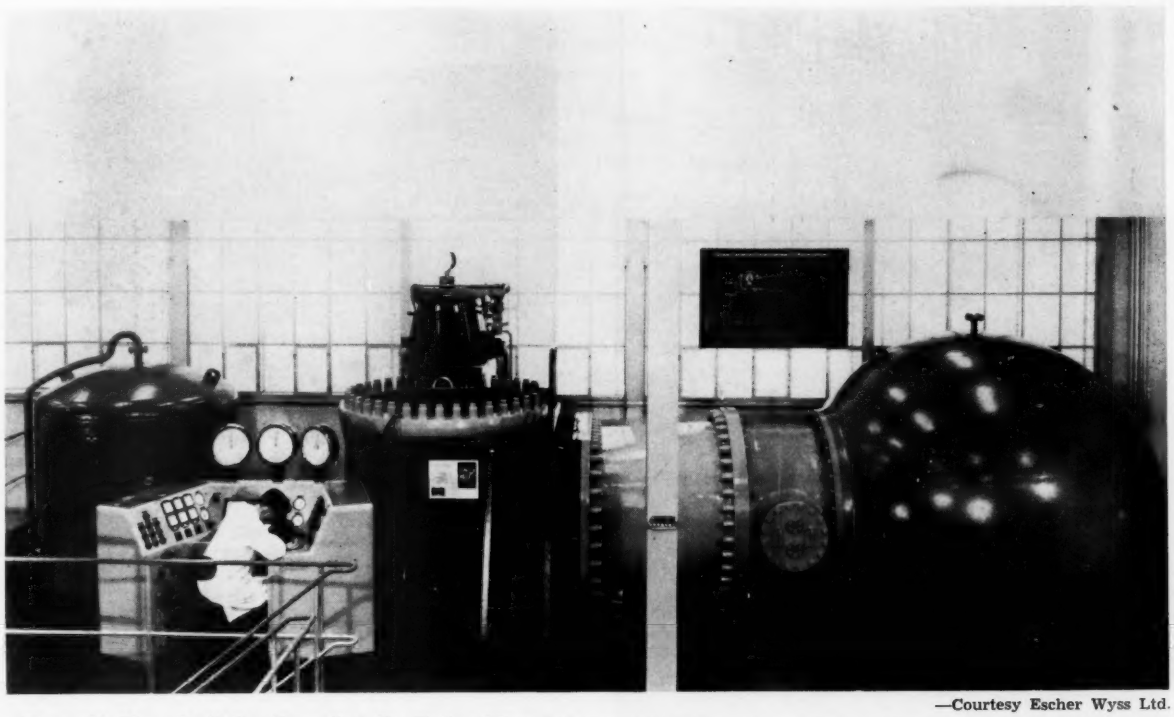
—Courtesy Chief Engineer Lennart Pehrsson

Figure 33. Cavitation Tunnel at the Karlstads Mekaniska Werkstad in Sweden. Control panel and measuring devices are in the foreground.

The Escher Wyss laboratories in Switzerland have long been a leader in hydrodynamic research. There, over 30 years ago, air was used as a more convenient fluid for studying hydraulic models, a practice now widely applied in ship model research. The laboratories support high quality design and production of diverse naval machinery including controllable pitch propellers, hydraulic pumps, gas turbines, and in time perhaps gas cooled reactors.

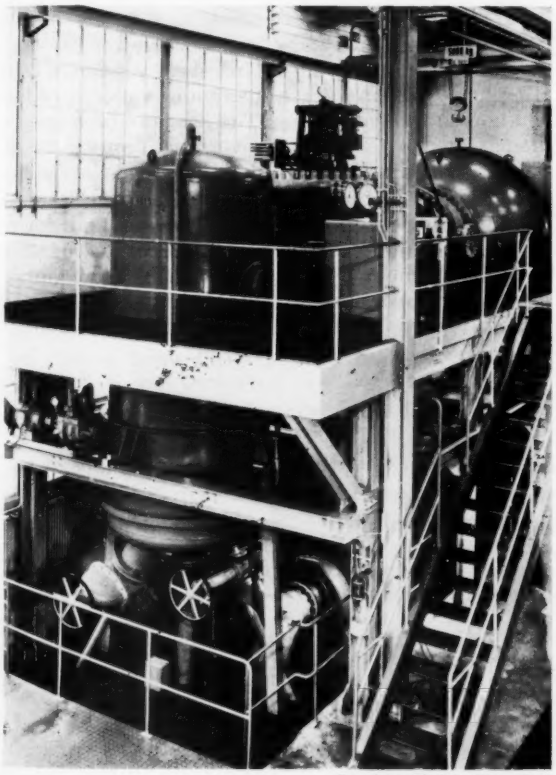
To permit cavitation observations at higher Reynolds numbers, a large variable pressure water tunnel was added in 1956 to the laboratory facilities of Escher Wyss (28). A single console, Figure 34, contains all operating and measuring controls, including the eyepieces for two optical systems for remote observation of cavitation from two directions. The 450 HP dynamometer on top of the test section has hydraulic transmission to the control console where the torque is weight-balanced. Two 400 HP driving pumps, Figure 35, will deliver against a pressure head of over 300 feet; however, the heavy test section withstands the static pressures so that the spiral casing of the model can be of light construction. At the time of visit to Escher Wyss, a model turbine runner test first showed striking cavitation swirls along von Karman vortex streets, and then was carried up to runaway cavitation conditions.

The Spanish cavitation tunnel at El Pardo is essentially the same design as the large tunnel at the Netherlands Ship Model Basin, together with a number of detail design alterations learned by con-



—Courtesy Escher Wyss Ltd.

Figure 34. New Cavitation Tunnel at the Escher Wyss Laboratories. From the pressure sphere, water flows to the left, through the hydraulic turbine model under test, to the tail water cylinder.



—Courtesy Escher Wyss Ltd.

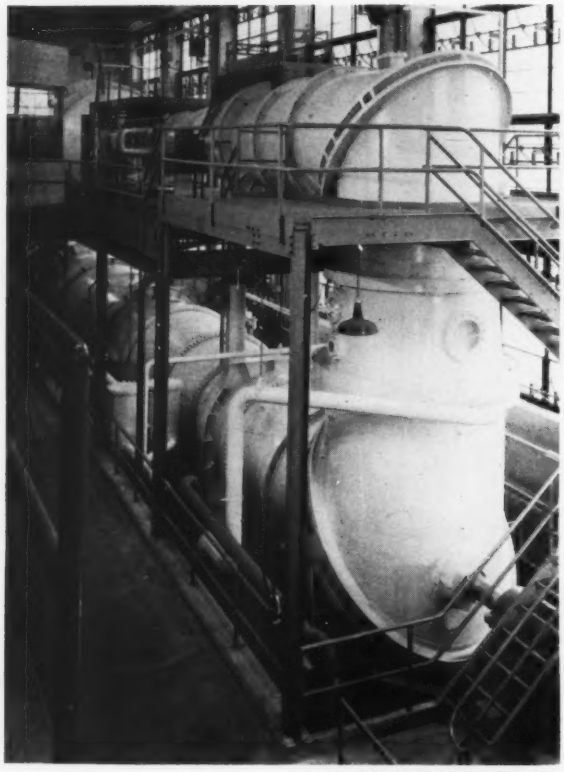
siderable operating experience at Wageningen. The El Pardo tunnel, erected in 1951, has a test section 36 inches square with rounded corners and an impeller motor of 300 HP.

The King's College tunnel was made from parts of a flow facility built originally in Germany for acoustic tests on underwater weapons (29). Its well-designed conversion to a cavitation tunnel provided the largest tool available for propeller research and it has been exceptionally well used. The 12-foot long test section for this tunnel, following a 5 to 1 contraction, is 40 inches high and 32 inches wide with rounded corners.

In Yugoslavia, a new cavitation tunnel, with a test section about 40 inches square, is currently being erected at the Zagreb Shipbuilding Research Institute. Interchangeable test sections will be provided.

Vospers Limited in Great Britain, long a leader in the development of high-speed small craft, is understood to have built recently a cavitation tunnel with a 20-inch square test section. This firm will no doubt make creative use of this facility in experiments on high speed propellers, with both axial and angular inflow, and in research on rudders and stabilizing fins.

Figure 35. Escher Wyss Cavitation Tunnel. From the tail cylinder, water is valved to two radial pumps connected either in series or parallel, thence to the bottom pressure sphere, and via a venturi to the top pressure sphere. Flow direction can be reversed for models operated as pumps.



—Courtesy of the Director

Figure 36. Largest Water Tunnel in the United States, Located at the Ordnance Research Laboratory, Pennsylvania State College.

At the Ordnance Research Laboratory located at Pennsylvania State College, a large tunnel was completed in 1950 for the purpose of testing complete self-propelled models of underwater bodies under controlled conditions (30). In the 48-inch diameter working section 14 feet long, water speed can be continuously varied to selected velocities up to 48 knots, Figure 36. The 95-inch, 4-bladed, adjustable pitch impeller is driven by a 2000 HP variable speed induction motor.

—Official U. S. Navy

Figure 37. 36-Inch Variable Pressure Water Tunnel Under Construction at Carderock. The resorber pit is 70 feet deep in bed rock lined with stainless clad steel.

The 36-inch variable pressure water tunnel now under construction at the David Taylor Model Basin (31) will have a vertical double-pass resorber with an outer cylinder 25 feet in diameter extending 70 feet below the ground elevation. It is estimated that bubbles entering the resorber with diameters of 0.015 inch or less will be reabsorbed into solution. Design of the new DTMB cavitation tunnel was materially assisted by tests of a 1/6-scale pilot model at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. In the full scale version, a 2880 HP pump will produce a maximum water speed of 50 knots in the test section. The absolute pressure on models under test will be variable from 2 to 60 pounds per square inch. Both an open jet and a closed jet test section are being constructed. Removable propeller shafts from both upstream and downstream directions will provide flexibility, together with independent dynamometer drives for counter-rotating propellers. It is expected that the DTMB tunnel, Figure 37, will be completed by mid-1958.

ACKNOWLEDGMENT

The gracious readiness of the various towing tank superintendents to furnish the photographs presented in this paper is gratefully acknowledged.

Apologies are made for failure to mention any new facilities unknown to the author, and for any unintended emphasis disproportionate to the importance of the facilities briefly described.

Appreciation is expressed to the Bureau of Ships for sponsoring participation in international tankery by the U. S. Navy of ultimate benefit to all maritime nations.

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THE UNITED STATES NAVY

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The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

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At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

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Never have our opportunities and our responsibilities been greater.

"ENGINEERING"

THE SOVIET ENGINEER AS A DESIGNER

ACKNOWLEDGEMENT

This article is one of a series written by Mr. E. P. Ward, a Deputy Editor of "Engineering," following a visit to the Soviet Union. It appeared in the 27 September 1957 edition of "Engineering."

No matter what facilities an engineer may have for practicing his art, the ultimate test of his skill is the quality of his products, and the ease and economy with which they are produced. In attempting to assess the Soviet engineer as a designer, I have considered the following requirements: Does the design meet the needs of the user and fit the conditions for which it is intended? How much attention is paid to finish and refinement? To what degree are the problems of production borne in mind by the designer? What part do imagination and innovation play in Soviet designs? What are the standards by which designs are judged?

DESIGNING FOR THE USER

In any problem of design the needs of the user must be considered first. But the user's needs can never be exactly ascertained: if a factory manager has never heard of spark erosion, how can he appreciate its value? Demand is the complex product of technical and economic intercourse—even in a Communist country.

In Britain and the West several complementary channels exist by which the customer can communicate his requirements to the designer—sales contacts, market and consumer research, advertising, consultation and the mechanism of the economic system generally. In a planned economy certain of these are excluded and the remainder are assumed by planning agencies, purchasing delegations, or research establishments. It appears to follow that consumer pressure in the Soviet Union can only make itself adequately felt at capital-equipment levels.

Mobile "embassies," or buying commissions, operate between industries, but generally at industrial rather than factory level. This system does not seem to be supplemented by the distribution of brochures or prospectuses. Thus one factory manager, whom I asked for descriptive literature, told me that "we have no need of advertising leaflets in a planned economy." Leaflets are occasionally printed but generally for export or exhibition purposes, rather than to lubricate internal commerce; though the monographs and up-to-the-minute texts prepared by research institutes may serve a similar purpose.

Such an approach is clearly inapplicable to the broader, diffuser market of the ultimate consumer. His basic needs—food, clothing, accommodation—can be recognized without much study, but the goods which add to his comfort or pleasure are less easily determined. Food supplies can be estimated on the basis of necessary calories and vitamins, but the ideal shape for a television set or a motor car can only be measured by a popularity rating. More difficult to judge is the relative demand, say, for refrigerators and washing machines. There is in addition the intangible demand for articles not yet in existence, a demand which must nevertheless be gauged if progress is to be made.

How does the Soviet Union approach these problems? Consumer demand has only recently been tackled seriously, and it is apparent that apart from traditional items Western consumer tastes are often used as a standard. Otherwise procedures are comparatively simple. If a store sells all its television sets within a few hours of delivery, then it is clear

that more should be ordered, and consequently produced. At this stage, consumer demand expresses itself in terms of quantity rather than design, though products which are longer established or relatively easy to produce in numbers may be of high quality. Thus although the image on a modern Russian television screen retains the bluish tint of earlier British sets, dolls and other traditional items are often of fine craftsmanship.

It is significant that in 1955 the Soviet Union with a population of 200 million had only 6 million radio receivers and 80,000 television sets; whereas Britain with one-quarter the population issued 9½ million sound licenses and 4½ million television licenses. It should be borne in mind, however, that the total number of radio reception points in the Soviet Union, including rediffusion, was 26½ million, while on the other hand a household in Britain with one radio license might have several sets. In Russia there are radio loudspeakers in many public places.

Unfortunately, the trial and error method of market study is not readily adapted to the development of new consumer products, and it seems that for this purpose a touchstone external to the Soviet Union is employed. Even the quality of Soviet-made machine tools is measured against Western machines, the characteristics of which are tabulated in detail. In general, I concluded that the customer became more articulate in his demand as his responsibility rose, from the level of individual consumer to that of an executive in major capital industry. The aptness of design might be expected to follow the same pattern.

A second question is concerned with the degree to which products fit the conditions for which they are intended. Soviet engineers appear to pay considerable attention to the design of special-purpose equipment—a logical consequence of living in a large country, where even a narrowly specialist machine may be required in sufficient numbers to make manufacture economical. The Russians are quick to recognize their own peculiar conditions and build accordingly. Thus, since distances are great, most cars have seats which fold to form emergency beds. An immense range of tractors are produced, from high stilted narrow-track models (DT 40), for cotton fields, to the C-100B, with tracks one meter wide, designed to operate in peat bogs (pressure on ground 0.24 kg. per sq. cm.).

I was interested to note that 60 per cent of the 500 or 600 machine tools made each year at the Sverdlov factory in Leningrad were designed for special purposes. This of course is no indication of overall Soviet practice, but I was told at Enims, the machine-tool research institute, that 789 types of "mass-produced" machine tools were made in 1955, while the projected figure for 1960 is 1,200. For a planned economy, in which duplication is avoided, these figures seem considerable, especially since they do not include the special machines produced. For example, at the ZIL commercial vehicle factory for its own purposes; ZIL has a single shop employing two shifts of 800 men devoted to tool production.

Much attention is paid to the use of local materials. Peat is abundant in Russia and black ridges where digging is in progress are a common feature of the countryside around Moscow. Considerable efforts have been made to use peat to best advantage both as fertilizer and as fuel, and the Shatura power station near Moscow is designed as a peat-burning plant. In Leningrad, experiments are in progress on peat-fired gas-turbines, though as in this country the development of a satisfactory commercial model has yet to be attempted. Coal in certain areas is distributed in thin seams, and underground gasification has been practiced for 15 years in such areas as Tula, Kuzbas and Donbas. A complete gas-turbine power station is being built at the LMZ turbine factory in Leningrad for use in conjunction with coal gasification. The plant, which is designed to operate with a gas temperature of 650° C, will have an output of 12 MW. It will comprise one high-pressure and one low-pressure gas-turbine, three air compressors, three gas compressors, two combustion chambers, two regenerators for incoming air, and four for the gas. A similar station of 25 MW is to be completed in a few years. No large gas-turbines have been built.

Conversely, it is sometimes possible to judge what materials are available from the types of plant constructed. Thus the almost exclusive concentration on enriched fuels in the Soviet atomic power program suggests that uranium diffusion plants have been operated on an enormous scale and that there are now considerable stocks of uranium 235, originally produced for military purposes. It also presupposes that by the time these stocks have been consumed the Soviet authorities expect to have either an alternative source of nuclear power, or a method of separating the uranium isotopes far more cheaply than by the conventional diffusion process.

Designers also take into consideration the extremes of cold found in parts of the Soviet Union and the poor road surfaces met in remote areas. Thus one motor truck (ZIL 157) is fitted with a device whereby the tire pressure can be varied from the cab during motion in accordance with changes in road surface—a low pressure affording an improved grip where slippery or loose surfaces are encountered. The GAZ 56 incorporates a differential

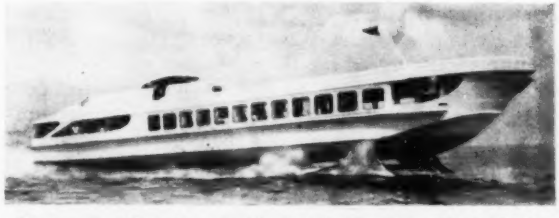

Figure 1. Adventure in Soviet design. The "Rocket" hydroplane made at the Gorky docks is an unconventional river boat capable of carrying 65 passengers at nearly 40 m.p.h.

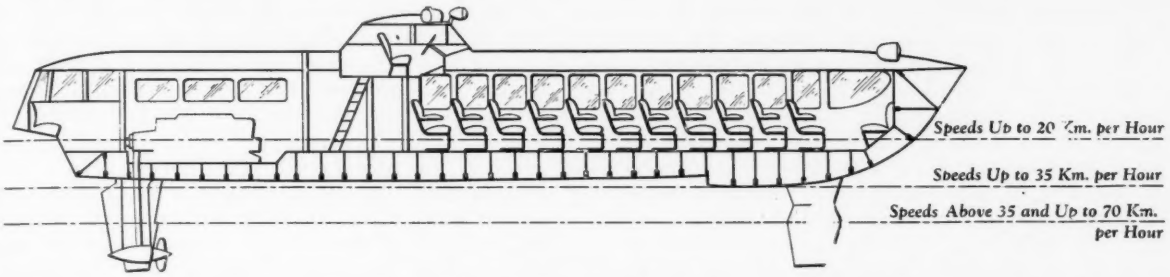

Figure 2. As its speed increases the "Rocket" is lifted hydrodynamically until its hull is clear of the surface. The air cushion under the hull serves to minimize pitching, rolling and other disturbances.

which in the event of wheelspin transmits 25 per cent of the engine's power to the non-spinning wheel. The MAZ 530 is a 40 ton truck with an exhaust-gas heating system designed to prevent loads freezing solid in cold weather.

The MAZ 530 also illustrates the tendency for equipment in the Soviet Union to be large. It is designed for use in conjunction with large excavators or draglines, where bucket capacity may exceed the complete load of smaller trucks. A projected walking dragline has a 100 meter boom and a bucket capacity of 25 cubic meters, with an estimated rate of working of 1,500 cubic meters per hour. Operated by seven men, or a minimum of four, it weighs 2,600 tons, requires an external electricity supply at 6,000 volts, and is driven by engines consuming a total of 10,120 kw. It is being built at the Uralmash factory. Draglines with 14 and 20 cubic meter bucket capacities are already operating. A 70,000 ton hydraulic press is also reported to have been completed, while LMZ have built for the Kuibishev scheme 20 Kaplan turbines each of 126 MW capacity, said to be the largest in the world. This emphasis on size is not unexpected; a vast country with largely unexploited resources makes a large-scale approach practicable, even necessary; indeed, the first words of the Soviet national anthem: "Shirokaya strana" mean "Wide country." Thus with such great distances to cover it is not surprising that a 400 kv transmission line is already in operation between Kuibishev and Moscow. Factories too are large by United Kingdom standards; the First State Ball Bearing factory has 10,000 employees and I was told that there were ten like it; while ZIL has 40,000 employees.

The size philosophy indicates that designers recognize the special conditions which obtain in the Soviet Union, but it can of course be carried too far. Thus, though small cars exist, the Moskvich for example, probably a major proportion of those on the streets in Moscow are so big as to represent a considerable wastage of fuel without providing a particularly enhanced service. The Soviet Union is, of course, not the only country that favors large cars. It is significant for us, perhaps, that the size philosophy is likely to prove attractive to the under-developed continents.

It seems clear from these examples that the Soviet engineer takes considerable pains to accommodate his designs to the conditions in which they will be used, but that the mechanisms for creative and dynamic evolution are often pedestrian. Nevertheless, the official U.S.S.R statistical abstract states that, in 1955, over a million inventors and "rationalizers" submitted over 2 million inventions, technical improvements and rationalization proposals of which 1,160,000 were introduced into production.

The number of suggestions accepted in one year in British industry has been estimated at roughly 360,000, with over a million submitted. Patents accepted during the same period were approximately 21,000, with nearly twice the number submitted. It should be borne in mind that the industrial working population in Britian is only 8 million as against roughly 17 million in the Soviet Union, though the population of the U.S.S.R. is roughly four times Britain's. In comparing these figures it should be realized that, in Britain, improvements introduced by production or design staff might not be included in these totals.

INNOVATION AND INVENTION

The fact that inventors and inventions are listed in an official book of statistics suggests that the Soviet authorities place a high value on innovation. There are, in fact, many indications of original technical thinking, even adventurousness, as may be gathered from the comparatively large hydroplane illustrated in figures 1 and 2. But there are also widespread signs of imitation.

Many machine tools in current use, though carrying the monogram of a Soviet factory, are so close in design to particular Western machines, that there can be little doubt that the Western tool has been used as a model, even allowing that similar applications require similar equipment. The Russians are not alone in this approach; I saw a facsimile of a Parker pen, identical with my own but for a Chinese inscription. Certain cars display a similar resemblance—one type of Moskvich, for example, appeares to follow an Opel design, even to the pattern on the radiator grille. When visiting the ZIL factory (formerly ZIS—S for Stalin), I had the temerity to

suggest to its director that the large ZIS automobile was almost indistinguishable from a well-known Packard. He explained very patiently that contemporary models were often similar; it was a matter of fashion. Had he asked me to distinguish between a 1957 Packard and a Cadillac I should have been at a loss. Nevertheless, the existence of photocopies of Western journals suggests that the Soviet authorities have no scruples about imitation if it can serve a useful purpose.

From the Soviet point of view such imitation is expedient. A country anxious to catch up to its rivals cannot afford to waste time plodding through routine work; better to copy accepted designs and proceed from there. During my interview with Academician P. I. Kapitsa, I put this proposition to him. He agreed.

But it would be misleading to suppose that imitation precludes invention. Many recent Soviet machine tools are of quite independent design. New techniques are continually being developed. I saw demonstrated at Tsnitmash (the heavy-industry research institute), a process whereby steel components as much as one square meter in cross-section could be welded together. Academician E. O. Paton, who invented the "flux-bath" process, has recently described it in London. The Russians have devised a novel method of continuous casting, on an incline, using facing link tracks. Nothing is ever entirely new, but items which were fresh to me included the use of a magnetically susceptible powder in conjunction with an electromagnetic field to grip delicate items, such as piston rings, for machining; a vibrator applied to a vertical boring machine to give a smooth finishing cut; the combination of high-frequency and ultrasonic methods to give rapid penetration in surface hardening; and the use of vacuum bells to enclose ladles of molten steel.

Improvisation in factories is quite common. Apart from the production of special-purpose machine tools at ZIL, I saw a neat and simple device, designed and built at the Electrosila works, Leningrad, whereby generator windings could be automatically taped with insulation. Another machine had been devised for automatically fabricating mica insulation—I was told that to perform this task automatically was extremely difficult, and it was the first such machine to prove successful. Comprehensive machinery exists to ensure that new ideas are quickly and widely incorporated in current designs.

The Russian is quite capable of solving problems in his own way. The visitor may be surprised to learn that Moscow's three-dimensional cinema was operating long befor the West made any commercial experiments in this direction. He may also be shocked to see his driver pass a red traffic light without even a guilty look. Later he may learn that red in this context does in fact mean much the same to a Russian as an Englishman; however, at a Moscow crossroads if the light is red, the driver may bleed right (since he drives on the right). The visitor may notice that there are two green lights (placed at the top) in addition to the amber. If one green is showing the motorist may proceed straight ahead; if two, then he may turn left. Sometimes Russian solutions are complicated, but they have their advantages.

FINISH AND REFINEMENT

Though not strictly a design consideration, finish is a quality that at least in Western eyes takes an important place. But it is reasonable to suppose that in a planned economy, where competitive sales do not apply, less attention is paid to superficial refinements. Experience confirms this. The Soviet engineer tends generally, at least in the domain of capital equipment, to be contented if a machine works well, irrespective of its appearance. Such an attitude has its advantages. The virtue of the T34 war-time tank and the more recent MIG fighter lay in their lack of refinements; in battle conditions refinements require too much servicing. Modern consumer products on the other hand are normally quite well finished—the clocks in all the cars I traveled in were running on time; a toy Petrushka with flexible arms and legs which I purchased was neat, well painted and strongly made; gramophone-record reproduction is of high fidelity.

Elsewhere, finish seems to be largely forgotten. Though all the drawing offices I visited were equipped with mechanical drafting appliances, the balance weights were usually crude castings. The steel cover plates shielding the Soviet Union's first power reactor appeared to be rough and ill-fitting. However, where care and accuracy was necessary—in the fuel elements, for example—the finish was of high order. The enriched-uranium fuel elements are cooled by pressurized water contained in stainless-steel channels. Since stainless steel is a voracious neutron absorber, the quantity present must be carefully limited, and precise manufacture is essential.

Nevertheless, high finish, even where it is not essential to the working of the product, may often be desirable. The operator with a smart lathe will tend to keep it clean, just as a smart soldier is likely to be a confident and efficient fighting man.

DESIGN FOR PRODUCTION

Utility is not the only criterion of design, for a product that cannot be made serves little purpose. The ideal design is one that both satisfies the customer and involves a minimum of labor, skill, materials and special tools in its production. How well do Soviet designs meet this requirement?

Reference has already been made to the Soviet industrial consumer's disregard for finish; in general too he prefers a simple to a complex product—"less to go wrong." Both these requirements simplify the designer's task. In addition, a considerable degree of standardization is acceptable; in Moscow certainly no more than 10 types of car, including earlier models of the same line, are normally seen, and

apartment houses, which are under construction in great numbers, are of closely similar pattern. A carefully co-ordinated standards system permits interlocking production; it operates through the industrial research institutes, such as Enims, which submits proposed standards to the All-Union Standards Committee. The systematic adoption of new production methods further assists the designer; thus spark or electro-erosion machines reduce the problems of die manufacture, and large hydraulic presses have been constructed from plate using the flux-bath welding technique. Printed circuits are employed for electronic equipment, while the use of tubular construction, not only for dragline booms, but also for tower cranes is already well established.

Enims keeps a close watch on production techniques, and formulates policy to secure the maximum economy. Thus I was told that the "main purpose of machine tools was to make articles not cuttings." With this object, a decrease in the number of universal lathes and an increase in grinding machines has been planned. In 1955, of the 98,000 production machine tools manufactured, 30 per cent were universal lathes; by 1960 output is planned to increase to 200,000 tools, of which only 20 per cent will be universal lathes. The aim is to increase casting production—and hence grinding—and reduce wasteful metal-cutting procedures. It is of interest that the production of lathes in the United Kingdom is just over one-quarter of total machine-tool production, though, excluding capstan and turret lathes, the proportion is not as much as 15 per cent. The United Kingdom production of grinding machines is probably about 10 per cent. Another technique designed to reduce metal wastage is a cylindrical trepanning tool. It consists of a hollow steel cylinder over a meter long with four double-edged cutters arranged symmetrically around the periphery at one end. The cutting edges project inside the cylinder and outside. The cylinder would be gripped in the chuck of a large drill or vertical borer, and a drilling cut made up to one meter deep. In this way part of the waste material (a central cylindrical bar) will be retained intact. Enims has, besides specialist design departments for different kinds of tool, a general design department concerned with such problems as strength, rigidity and vibration, and another for the study of materials.

With these advantages, the Soviet designer is equipped to prepare practical and economic designs. A comparison between Soviet and British productivity in particular industries might give some indication of his success. Unfortunately, satisfactory comparative figures are not available. The British machine-tool industry in 1956, employing nearly 46,000 men, produced 155,000 tons (deliveries) of equipment. The Soviet industry produced 250,000 tons (roughly 120,000 tools), with nearly four times as many men—the Soviet machine-tool industry is said to have a trade-union membership of 180,000. The only conclusion to be gathered is that Soviet productivilty is lower than Britain's, but the comparison depends on the assumption that the types of tool produced are comparable. If due margin of error is allowed, the two productivities can be regarded as roughly similar. A weakness of this comparison is Soviet concentration on capital industry, leading to a greater proportion of heavy machines (3 per cent of total Soviet production comprises large units made to order). Machine tools are also built by factories for their own purposes, as at ZIL —a practice far less common in Britain.

In a year ZIL, with 40,000 employees, produces some 120,000 buses and motor lorries. The entire British annual production of commercial vehicles amounts to between 300,000 and 350,000, little more than twice the Soviet figure for one factory. The total number of employees in the British motor industry is between 300,000 and 450,000, something like ten times that employed at ZIL, but including, of course, those engaged on motor-car production, accounting perhaps for two-thirds or three-quarters of the total. Thus it can be seen again that productivity is of the same order in Britain and the U.S.S.R. It should not, of course, be overlooked that ZIL makes many of its own special-purpose tools; but, as against this, it concentrates, apart from bus production, on only one kind of 4 ton truck.

These comparisons are, of course, very unsatisfactory, but with the other considerations mentioned lead to the general conclusion that Soviet designs are at least as easy to produce as Western equivalents.

CRITERIA OF DESIGN

One of the functions of the industrial research institutes is to maintain and improve standards of design. The catalogue of Western machine tools I saw at Enims, for example, represented a standard by which Soviet tools could be judged—"to ensure that tools were not worse than foreign samples." I asked how the Soviet Union would manage if there were no Western world to set the pace. There were, I was told, three categories—standard, above standard and below standard. Designs below par were eliminated, and efforts were constantly made to raise the level. This was a substitute for competition. Where a factory fell particularly below standard on design or production, an inquiry would be held and the management might be replaced.

Apart from the problem of knowing exactly where to place the standard, this approach seems to lead to certain difficulties. For linear development it might be admirable, as in designing machine tools of greater accuracy or higher cutting speeds. The solving of existing problems could be tackled in the same way. But to initiate completely new developments, such a mechanism must surely be inadequate. Thus, given radio, television is merely a matter of solving a number of technical problems; but to envisage—and exploit—radio itself required an entirely different approach. Similarly, if the idea of a jet engine

has already been formulated, then with a sufficient concentration of men and money a practical working unit can be developed.

The Russian is an inventive as the next man, but is his system sufficiently flexible to accommodate invention? Invention—of a creative rather than a problem-solving kind—is a disturbing influence requiring a constant readjustment of any industrial program. Where ideas serve an existing purpose, they are no doubt welcomed and put to use, but are they equally acceptable when they mean revision of an adopted five-year plan? The Soviet designer fits his work well to the needs of user and producer, but can he change course in mid-stream?

A significant increase in research effort, both basic and applied, characterized the year 1957. The largest single program was the $250 million project, IGY. This world-wide study involved the cooperation of 56 nations and more than 5000 scientists and engineers. The scope of applied research in the field of atomic energy is pointed up by the facts that 120 reactors were in operation or under construction, and that an estimated $400 million was saved to United States industry through use of radio-isotopes. Electronics research pushed forward in the fields of semiconductors, long range radar, and electroluminescence. The broad field of materials advanced particularly in the areas of metals, plastics, ceramics and fibers. A total of about $7 billion was contributed to research by industry and $3 billion by the government, according to the McGraw-Hill Department of Economics.

—from "The Frontier," organ of the
Armour Research Foundation

HARWICK JOHNSON

TRANSISTORS—A SIMPLIFIED EXPOSITION

THE AUTHOR

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INTRODUCTION

THE INVENTION of the point-contact transistor by Bardeen and Brattain[1] and of the junction transistor by Shockley[2] signified the advent of a long dreamed of practical solid-state amplifying device. The promise of the transistor to modern electronics may be compared, in many respects, to that of the vacuum tube to an earlier era. Modern technology thinks in terms of personal communication—the "walkie-talkie" and personal radios—in terms of large and complex computing machinery, or in terms of the intricate and compact electronic systems vital to flight vehicles. In all these areas the common need to conserve space, weight and power and achieve reliability is best served by the transistor. The availability of the transistor makes it possible for us to go beyond the practical limit which would be set by vacuum tubes in this advancing technology.

With our communications and complex control systems so highly dependent on electronics, it is of interest to look at the details of the device around which many of these systems are built. For the capabilities and limitations of the device will be reflected in the capabilities and limitations of the electronic system itself. In this article we will attempt to build, from the elementary phenomena concerned, an appreciation for the capabilities and limitations of transistors. We will make many simplifications which will belie the complexity of the basic mechanisms involved. Our major concern is with the transport of charge carriers (e.g. electrons) through a solid where their motion is greatly affected by the atoms making up the solid. This situation is inherently more complex than in a vacuum tube where the electrons, once free of the cathode, can be moved and controlled without hindrance through the vacuum. On the other hand, those of us concerned with electronic systems find few occasions to ask about the basic mechanisms involved in the conduction of current through a copper wire. Ohm's law or, in more complex situations, Maxwell's equations tell us most of what we need to know for electronic applications. Thus we may be concerned with the velocity of propagation of an electrical signal on a wire but do not need to ask for the drift velocity of the electrons. We may pass large currents through the copper without concern for space charge effects. We need not ask whether the charge carriers are electrons or holes. We may vary the temperature over wide limits with relatively little change in the conductivity of the copper. We may even add impurities to the copper, in amounts that wou'd completely change the behavior of a semiconductor, without seriously affecting the conductivity of the copper. To develop an appreciation for the capabilities and limitations of transistors we will have to ask these and other questions about the properties of semiconductors.

SEMICONDUCTORS AND CRYSTAL STRUCTURE

Solids may be conveniently, if loosely, classified into metals, semiconductors and insulators according to their room temperature electrical conductivity. Metals are good electrical conductors and there is about one electron per atom (or about 10^{23} electrons/cm^3) available for conduction. In a pure semiconductor like germanium there is available for conduction at room temperature only about one electron per 10^{10} atoms (or about 10^{13} electrons/cm^3) and the conductivity is low compared to that of a metal. However, in an insulator there may be but one electron per 10^{18} atoms (or about 10^5 electrons/cm^3) and the electrical conductivity is extremely small. These large differences are due to differences in the electronic structure of the atoms making up the solid and to the manner in which the solid is built up from the elementary atoms.

For purposes of exposition we will consider germanium, the most widely used transistor semiconductor. The germanium atom has four valence electrons and germanium forms a crystal in which each germanium atom is surrounded by four other germanium atoms. With this geometry each germanium atom can share a valence electron with each of its four nearest neighbors in a three-dimensional lattice. This type of bond between atoms is termed a covalent bond and the crystal is often referred to as a valence crystal. Such a system of linking atoms is depicted in Figure 1 in a two-dimensional representation.

In such an ideal crystal there are just enough valence electrons to fit into the binding structure and the crystal would be a perfect insulator since there are no surplus electrons free to carry current. However, at temperatures above absolute zero, thermal agitation enables some electrons to break away from the valence bond and these electrons are free to wander through the crystal and conduct current. As indicated earlier, in pure germanium only one electron for each 10^{10} atoms is statistically able to do this at room temperature. Such a semiconductor is said to be an intrinsic semiconductor.

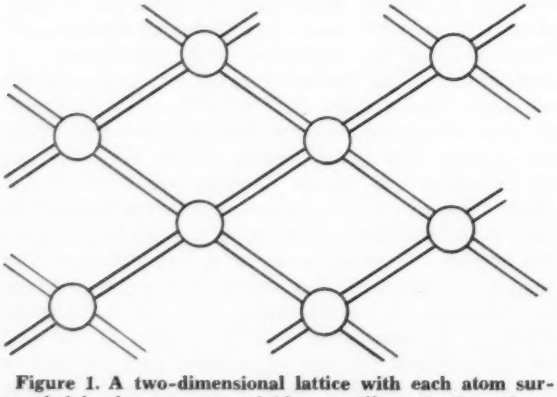

Figure 1. A two-dimensional lattice with each atom surrounded by four nearest neighbors to illustrate the valence bonds in germanium.

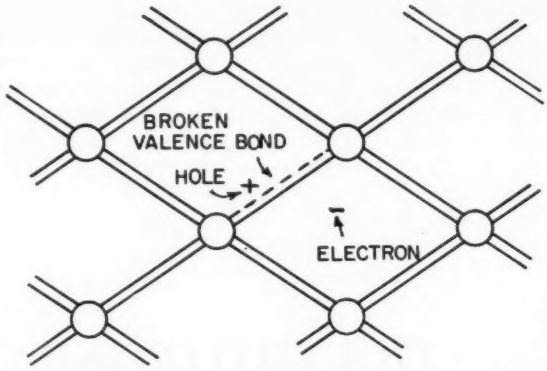

Figure 2. Creation of an electron-hole pair in crystal by breaking of valence bond.

For each free electron that is created by thermal agitation there is left behind an unfilled valence bond. This vacant bond may be satisfied by the transposition of a near-by valence electron so that the vacancy or absence of an electron will also appear to wander through the crystal. (Figure 2.) In this process charge is being transferred and hence electrical currents may be conducted by this process. A negative charge (i.e. that of an electron) is being transferred in a direction opposite to that of the motion of the vacancy. However, it is more convenient to consider the vacancy to carry a positive charge along with it and treat the vacancy as though it were a particle similar to the electron but with a charge of opposite sign. It should be appreciated that this treatment of the vacancy, which is called a hole, is a formalism and no actual physical significance should be attached to the positive charge other than the absence of an electron.

It should be noted that in an intrinsic semiconductor electrons and holes are created in pairs. Their creation requires the breaking of a valence bond so that it may be reasonably surmised that the number of free electron-hole pairs for a given temperature will depend very strongly on the strength of the bond in a given material. We shall have occasion to return to this consideration in a discussion of different semiconductor materials for transistors. Valence bonds may also be broken by illuminating the crystal with light. This is the phenomenon of photoconductivity.

In a discussion of the electrical properties of a semiconductor, it is convenient to have an energy representation for the state of the electron—that is, whether it is bound or free to wander through the crystal. This is conveniently done in the form of an energy band diagram shown in Figure 3. In our ideal valence crystal, all electrons would be considered as satisfying the crystal bonds and residing in the valence band completely filling it. Above the valence band is a forbidden energy region which we may take as a representation of the energy required to release an electron from a covalent bond. An elec-

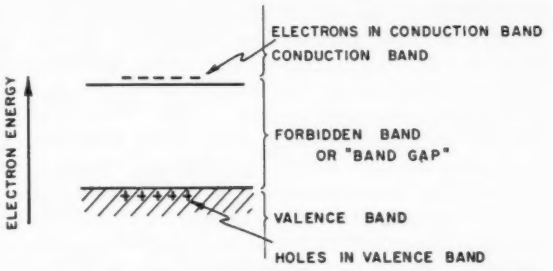

Figure 3. Energy band diagram for an intrinsic semiconductor. Electrons and holes result from breaking of valence bonds.

tron so released may then be thought of as being raised to the conduction band and leaving behind a hole in the valence band. The separation between the conduction and valence bands is referred to as the bandgap.

Having taken considerable time to develop the concepts of an intrinsic semiconductor, it may later be disconcerting to realize that the electron-hole pairs contributed by the germanium atoms play little direct beneficial part in transistor devices. (A major exception to this is in photo-electric transistor devices.) In most instances in the transistor their direct effects are depreciative—but this plays a part in the limitations of transistor devices which will appear later.

The additional carriers (electrons and holes) which are directly utilized in transistor devices are obtained by substitution of very small amounts of impurity atoms in the pure crystal. Thus if arsenic having five valence electrons is substituted for a germanium atom, there is one more electron than is required to satisfy the four covalent bonds. See Figure 4. This additional electron is very loosely bound and very little energy is required to free it to wander through the crystal. Thus in our energy band picture, Figure 5, the energy level associated with this electron when it is associated with the

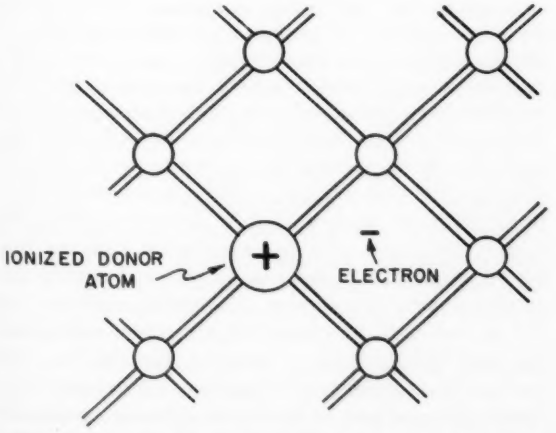

Figure 4. Substitutional donor impurity atom gives up its additional electron not required to satisfy the crystal bonds.

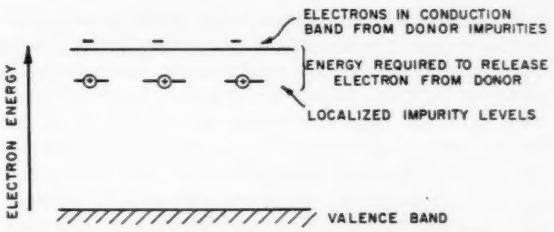

Figure 5. Energy band diagram showing energies associated with substitutional donor atoms.

arsenic atom is indicated only a very small distance below the conduction band. For commonly used impurities such as arsenic and antimony in germanium, thermal energy at room temperature is more than adequate to assure that the additional electrons from all the impurity atoms are raised to the conduction band. Such an impurity conductor is said to be n-type and the impurity is called a donor. Since the impurity (arsenic in this example) is a neutral atom when it has its five valence electrons, the loss of an electron leaves it with a net positive charge. However, this positive charge is fixed to the site of the arsenic atom and is not free to move through the crystal. It will appear that these fixed charges play an important part in the functioning of the transistor. It should be noted that, in contrast to the intrinsic semiconductor in which electrons and holes were created in equal numbers, an impurity semiconductor may have a preponderance of one type of carrier.

It is now a simple extension of the above to realize that if an impurity such as indium or gallium having but three valence electrons is substituted for a germanium atom, a vacancy or hole would be created (Figure 6). Such an impurity is called an acceptor since it accepts an electron from a neighboring germanium atom to complete the unfilled bond and the impurity semiconductor is said to be p-type.

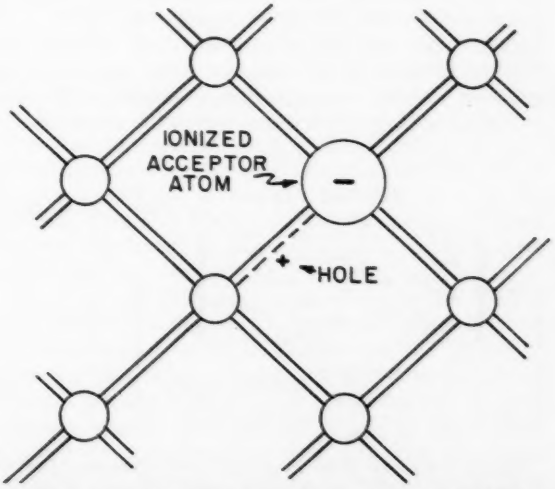

Figure 6. Substitutional acceptor atom having insufficient electrons to satisfy crystal bonds creates a vacancy or hole.

Much has been said about the stringent requirements in purity and crystal perfection demanded of transistor materials. An appreciation for this may be obtained by considering the impurity concentrations that may be used in transistor materials. It has earlier been indicated that in intrinsic germanium about 10^{13} electron-hole pairs/cm^3 are created by thermal agitation at room temperature. If conduction due to electrons from donor impurities is to predominate, it is evident that the impurity concentration must be somewhat greater than that. A typical value for transistor material might be 10^{15} impurity atoms/cm^3 (corresponding to material of conductivity about 1 mho/cm). This impurity concentration corresponds to one impurity atom (e.g. arsenic) for every 100,000,000 germanium atoms. That is, the impurity semiconductor is still 99.999999% pure. Although such a crystal is called a doped crystal, it is still extremely pure by ordinary chemical standards. Moreover since transitor manufacture requires careful control over the addition of even these small amounts of impurity, the pure germanium starting material must be of even greater purity.

In addition to this very high degree of chemical purity, transistor materials must also have a high degree of crystalline perfection. Germanium atoms misplaced in the lattice may give rise to unfilled bonds and hence to the creation of holes, so that electrically the crystals may appear quite impure. Other crystalline imperfections will impede the flow of carriers through the crystal, annihilate electron-hole pairs by enhancing their recombination, or constitute traps reducing the number of carriers available for conduction.

CURRENT FLOW IN A SEMICONDUCTOR

To understand the operation and limitations of the conventional bipolar transistor it is well to discuss first some of the general features of two mechanisms of current flow. The first of these will be the familiar "drift" flow of charge carriers as in a copper wire carrying a current. The second is a "diffusion" flow along a charge-carrier concentration gradient such as occurs in gaseous discharge devices.

Consider then the familiar "drift" current flow in a strongly n-type semiconductor connected across a battery as in Figure 7. The current is carried by electrons moving along the bar under the influence of the electric field. The magnitude of the current depends on the electron density, the strength of the electric field and the ease with which the electrons can move through the crystal lattice of the semiconductor. The electron motion is not the unhindered straight-line flight as in a vacuum but is greatly impeded and randomly altered in direction by collisions with the crystal lattice. Nevertheless, since the impressed electric field is continually exerting a force to move the electrons in the direction of the positive electrode, there results a net motion of electrons in this direction and hence a current flow (which according to convention is in the opposite direction). The ease with which a charge-carrier can move through the lattice is an important electrical property of the solid and is measured in terms of a mobility. This is quite simply the net average velocity attained by the charge carriers in the solid under the influence of a unit electric field. However, it should not be presumed that a high mobility is sufficient to make a material a good conductor. Thus while the mobility of electrons in germanium is about one hundred times that in copper, copper is a much better conductor because of the vastly greater number of electrons available for conduction as explained earlier.

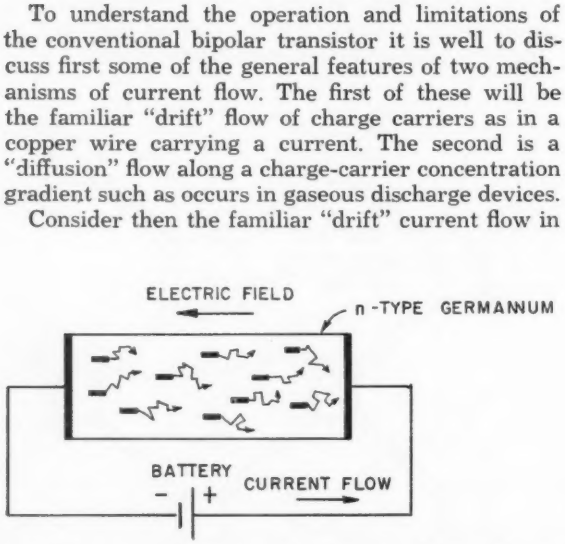

Figure 7. Current flow in n-type semiconductor. Current is carried by "drift" of electrons under influence of electric field. The irregular paths are due to collisions with the crystal lattice.

An important feature of this familiar type of current flow is that conduction occurs without the introduction of excess charge carriers into the solid over the number normally there under equilibrium conditions (battery disconnected). As soon as one electron is removed at the positive electrode another electron is transferred from the negative electrode into the semiconductor. Thus large currents can be carried without altering the charge density in the solid. Indeed, in a homogeneous semiconductor, extremely large fields would be required to maintain even a very small deviation from the equilibrium charge density.

However, excess charge densities can be set up by current flow in non-homogeneous regions of a semiconductor as exemplified by a p-n junction. We will defer a discussion of how this comes about to consider here how a diffusion flow of charge carriers may result from a non-equilibrium distribution. For example, let us arbitrarily assume some mechanism provides us (but without restraints on carrier motion) with an excess charge density distribution within the body of a semiconductor such as that shown in Figure 8. Because of thermal energy and collisions with the lattice, the excess carriers will diffuse through the crystal in a random-walk manner and tend toward a uniform distribution. The net result is evidently a transport of charge carriers from one part of the semiconductor to another and hence a current flow during the process. The magnitude of the current at any instant will depend

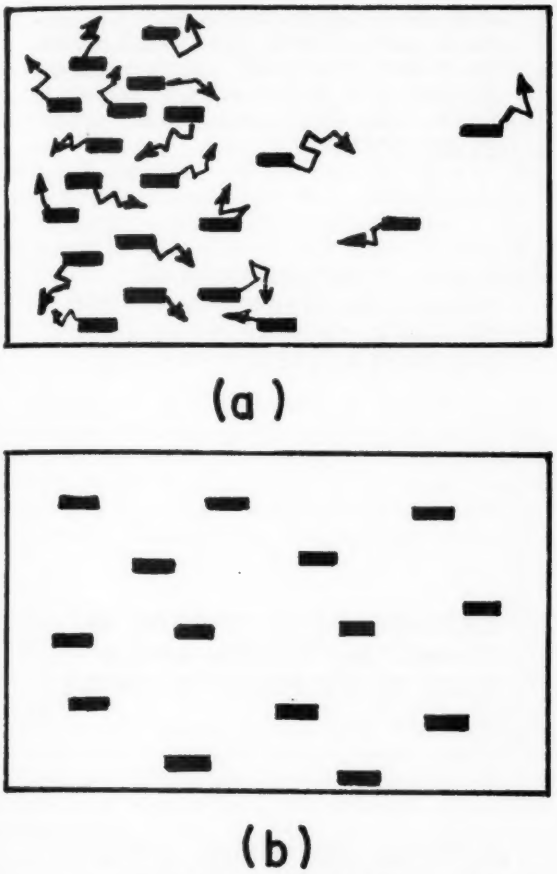

Figure 8. An initial excess non-uniform charge distribution (a) will tend towards a statistically uniform distribution (b) by diffusion due to thermal motion. In the process, charge is transported and a diffusion current flows. No electric field is applied.

on the gradient of the charge-carrier concentration, since a large gradient means there are a greater number of charge carriers that have to be redistributed to achieve a uniform distribution. It also depends on the ease with which the charge carriers can move through the crystal, a factor discussed above. It is important to recognize that the mechanism of this process has involved only the thermal energy of the excess carriers and does *not* involve an electric field. The diffusion flow would have occurred whether or not the particles carried an electric charge. But because we are concerned with charged particles (electrons or holes) a current flow results from this diffusion flow.

Since only thermal energy is involved in diffusion flow it is readily appreciated that current flow by this means is much slower than can be realized by impressing an electric field to attain a drift current flow. Diffusion flow in the base region of a transistor corresponds in velocity to a drift flow velocity that would be attained in a voltage drop of only 1/20th of a volt.

THE P-N JUNCTION

Having discussed above, in a qualitative manner, the nature of a semiconductor and the general features of current flow through a semiconductor, we next consider the p-n junction. The properties of the p-n junction form the basis for all bipolar transistor devices. These are devices in which both types of mobile carriers (holes and electrons) play an essential role. But even in many unipolar devices, whose operation depends primarily on one type of charge carrier, p-n junctions may be employed.

A p-n junction is a single crystal semiconductor with two contiguous regions having conductivities of opposite types. However, to develop an appreciation for the reasons for the basic behavior of a p-n junction, it is convenient to consider a p-n junction to be formed by bringing together a p-type semiconductor and an n-type semiconductor as in Figure 9. Recalling that the p-type material contains many mobile holes derived from acceptor impurities, and the n-type semiconductor contains many mobile electrons derived from donor impurities, it may first be expected that these mobile carriers would diffuse throughout the composite crystal toward a uniform distribution for both holes and electrons. However, we shall see that restraining forces are set up in the immediate vicinity of the p-n junction that keep the bulk of the holes in the p-type region and the bulk of the electrons in the n-type region.

The p-type region (and also the n-type region) is originally electrically neutral with the charge carried by the mobile holes exactly compensated by the fixed negatively ionized acceptor impurities (Figure 9). Now as the holes tend to diffuse out of the p-type region into the n-type region, the fixed charges are no longer electrically compensated and give rise to a negative charge density near the transition region between the p- and n-type materials. This negative charge being opposite to that of the holes will retard the flow of holes out of the p-type region. Similarly, diffusion of electrons out of the n-type region results in an uncompensated positive fixed charge density on the n side of the junction. The tendency for mobile charges to diffuse across the junction sets up restraining forces in the form of uncompensated fixed charges which act to keep the holes in the p-type region and the electrons in the n-type region.

Thus, in the transition region of a p-n junction there is a region depleted of mobile charges leaving the uncompensated fixed charges on the impurity atoms in sort of an electric dipole. This transition region is variously referred to as the barrier region, depletion region, space charge region or exhaustion region. It is the properties of this barrier which, as we shall see, permits current to flow easier in one direction than in the other that makes the p-n junction an efficient electrical rectifier.

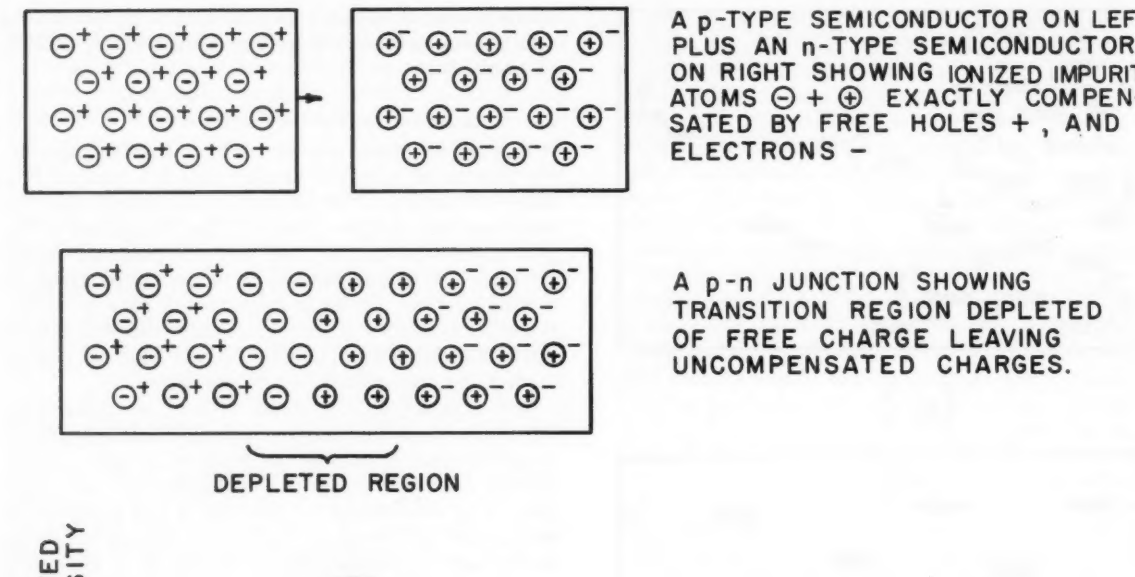
A p-TYPE SEMICONDUCTOR ON LEFT PLUS AN n-TYPE SEMICONDUCTOR ON RIGHT SHOWING IONIZED IMPURITY ATOMS ⊖ + ⊕ EXACTLY COMPENSATED BY FREE HOLES +, AND ELECTRONS −
A p-n JUNCTION SHOWING TRANSITION REGION DEPLETED OF FREE CHARGE LEAVING UNCOMPENSATED CHARGES.
DEPLETED REGION
UNCOMPENSATED CHARGE DENSITY
UNCOMPENSATED CHARGE IN TRANSITION REGION GIVES RISE TO AN ELECTRIC DIPOLE
ELECTRON ENERGY
FORCE ON ELECTRON
FORCE ON HOLE
INTERNAL POTENTIAL ENERGY AND DIRECTION OF FORCE EXERTED BY UNCOMPENSATED CHARGES ON FREE ELECTRON OR HOLE IN TRANSITION REGION.

Figure 9. A p-n junction and restraining forces on electrons and holes.

CURRENT FLOW IN A P-N JUNCTION

Minority Carrier Lifetime and Recombination

In order to discuss the nature of current flow through a p-n junction, it will be necessary to introduce another basic concept concerning the free carriers in a semiconductor. In our discussion of an intrinsic semiconductor we drew a picture of the creation of hole-electron pairs by the breaking of valence bonds due to thermal vibrations. This is not only a continuing process in the semiconductor but also a reversible one. That is, a free electron wandering through the crystal may drop into an unfilled valence bond resulting in the annihilation of an electron-hole pair. This also is a continuing process and when we speak of a free charge carrier density we refer to the net statistical carrier density resulting from the competing processes of generation and recombination. It should be mentioned that the direct recombination process noted above is a rather unlikely one in practical semiconductor materials. More often recombination takes place through the intermediary of a third party sometimes referred to as recombination center. This may be an impurity atom such as copper or nickel in germanium, or it may be a structural defect in the germanium crystal. Semiconductor surfaces, since they represent the termination of the crystal lattice and are also subject to chemical reactions with the ambient, are very often the sites of large numbers of recombination centers. Another consequence of this process of gen-

eration and recombination is that if we succeed in injecting an excess charge density, say of holes in n-type material, the excess density of holes will decay with time to the equilibrium hole density.

From a process of continual generation and recombination we may conceive that the mobile charges have a statistically finite average lifetime in the free state. This is referred to as the carrier lifetime and, in particular, as the minority carrier lifetime in semiconductor devices where our attention is often concentrated on the minority carrier. While the charge is in a free state, it wanders through the crystal and the statistical average distance it moves before being lost through recombination is referred to as the diffusion length.

Lifetimes in pure germanium of the order of one-hundredth of a second have been measured. This corresponds to a diffusion length of almost one centimeter. In doped germanium of the type used in transistors the carrier lifetime is more like one-ten-thousandth of a second, or less, with a corresponding diffusion length of less than one-tenth of a centimeter.

Saturation or Reverse Currents

While the reverse current of a p-n junction is not of as direct interest in transistors as the forward current, it is directly related to the forward current and, moreover, is one of the limiting factors of transistor operation. We have seen that at the transition of a p-n junction there exists an electric dipole or an internal potential difference (Figure 9) which tends to keep the holes in the p-type region and the electrons in the n-type region. Now in the n-type region there are, in addition to the electrons derived from the donor impurities, a much smaller number of holes due to the breaking of valence bonds by thermal vibration. Then the same force which restrains the holes from leaving the p-type region will also tend to collect holes from the n-type region moving them across the junction into the p-type region. Under equilibrium conditions, this flow of holes across the junction may be considered to be exactly balanced by the flow of holes from the p-type region tending to diffuse across the junction so that the net hole current is zero.

If a potential is applied to the junction in the reverse direction, this applied potential simply appears across the transition region increasing the internal potential difference (Figure 9) or barrier. This sweeps away holes in the n-type region in the immediate vicinity of the junction forcing them into the p-type region. The only holes in the n-type region that are available to be transported across the junction are those created by thermal vibrations within a diffusion length of the junction. Otherwise they are lost by recombination and do not reach the junction. This hole current across the junction may be represented by Figure 10. The hole density near the junction is zero since these are immediately swept away, while at about a diffusion length, L_p, from the junction the hole density has its equilibrium value,

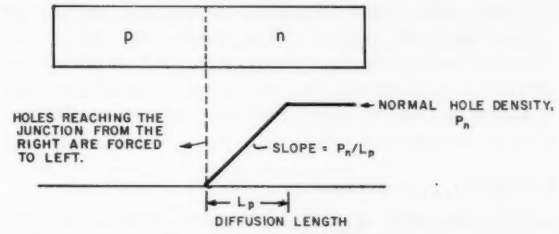

Figure 10. Origin of hole saturation current from thermally created holes in n-type material diffusing to the junction. Diffusion current is proportional to slope, p_n/L_p.

p_n. This establishes a hole density gradient, p_n/L_p, giving rise to a diffusion flow of current as discussed earlier,

$$I_s \propto p_n/L_p \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Even for a small applied potential (about 1/40th of a volt, the holes in the vicinity of the junction are effectively removed to produce the situation depicted in Figure 10. Once this situation is established further increases in the reverse bias do not affect the hole density gradient responsible for the flow of current. This current is then *independent* of the applied voltage and is called the saturation current, I_s. This current is quite small since there are relatively small numbers of holes in n-type material.

For subsequent consideration it is well to point out that since the holes in the n-type material are obtained from the breaking the crystal valence bonds, the saturation current is directly dependent on the semiconductor material. Also, in n-type doped materials the equilibrium density of holes is reduced as donors are added since this increases the supply of electrons to satisfy broken bonds. Thus the saturation current will also depend on the donor concentration or the conductivity of the material.

This discussion has concentrated only on the motion of holes across the junction. It is obvious that entirely analogous considerations apply to the mobile electrons giving rise to an electron component of

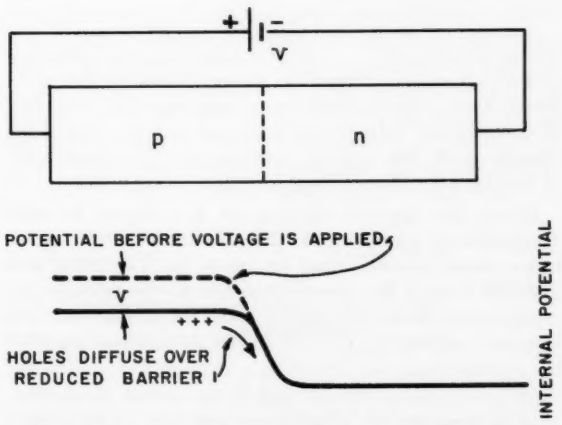

Figure 11. A large forward current flows when the barrier is reduced by an applied voltage.

current which must be added to the hole current to obtain the total current. This procedure will be followed throughout this paper with the detailed descriptions considering the motion of holes. The reader is asked to bear in mind that an analogous situation always exists for electrons.

Forward Current Flow

Consider now a voltage applied across the p-n junction in the forward direction (Figure 11). This voltage also will appear internally across the transition region but now is in a direction to reduce the barrier which prevented the holes from diffusing into the n-type region. (As before our discussion will concentrate on the hole motion keeping in mind analogous considerations apply to the electrons). With the barrier now lowered, many holes will flow or be injected into the n-type region. These are excess minority carriers over and above the number normally in the n-type region. To preserve electrical neutrality additional electrons are simultaneously fed in at the ohmic contact to the n-type region. Since electrical neutrality is preserved, high electrical fields are not involved in the n-type region itself. *This important property of a p-n junction to introduce excess carriers into a semiconductor makes possible the conventional or bipolar transistor.*

Even as the reverse saturation current was determined by a diffusion flow, we shall now see that the forward current is also determined by a diffusion flow. The holes surmounting the barrier diffuse away from the junction and are gradually lost by recombination so that at a diffusion length away from the junction the *excess* hole density is reduced essentially to zero. The hole density at the junction is an exponential function of the amount the barrier is lowered (i.e., by the applied voltage). See Figure 12. The hole density gradient responsible for the diffusion flow is then,

$$\frac{\text{const} \times e^{\frac{q}{kT}V}}{L_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where $\text{const} \times e^{\frac{q}{kT}V}$ is the injected hole density, and the forward current is proportional to this gradient. Since the current is an exponential function of the applied voltage, the forward current increases rapidly with the applied voltage and the impedance of the forward biased p-n junction is very low.

When the applied voltage, V, is reduced to zero (equilibrium conditions), the injected current, as we have noted before, must be equal to the saturation current so that the constant in the above relation by comparison with Equation 1 must be p_n. Indeed, the injected current is related to the saturation current by

$$I = I_s e^{\frac{q}{kT}V}$$

The total current is the difference between the injected and saturation currents since they flow in opposite directions and is

$$I = I_s (e^{\frac{q}{kT}V} - 1),$$

the familiar diode relation whose current-voltage characteristic is shown in Figure 13. It is worthwhile to point out that the rectification properties of a p-n junction have no direct relation to the proportion of the current being carried by holes or electrons. On the other hand for efficient use of a p-n junction as the emitter of a transistor, it will be necessary to control the situation so that the current is carried almost entirely by one type of mobile carrier.

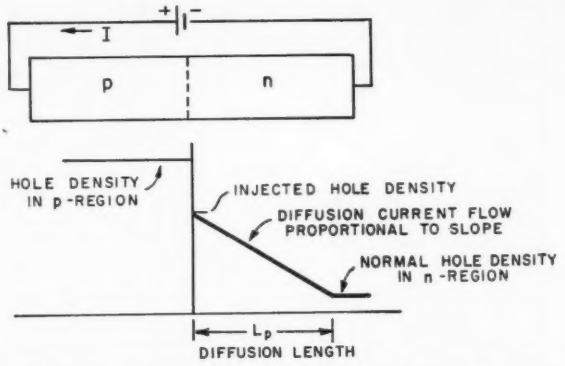

Figure 12. Forward hole current determined by diffusion flow of holes injected into n-type region.

THE BIPOLAR TRANSISTOR

From the above discussion of the properties of a p-n junction it is but an elementary step to consider the basis of operation of the conventional bipolar transistor. Structurally, the simple bipolar transistor is a semiconductor having three regions of alternating conductivity types (p-n-p or n-p-n). It thus contains two p-n junctions back to back. If these junctions are far apart so that an injected density of minority carriers in the middle region is lost through recombination before it can diffuse to the opposite junction no transistor action will be obtained. Therefore, the junctions must be spaced less than a diffu-

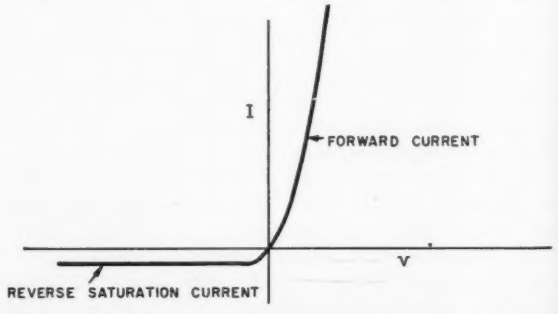

Figure 13. Current-voltage characteristic of p-n junction diode.

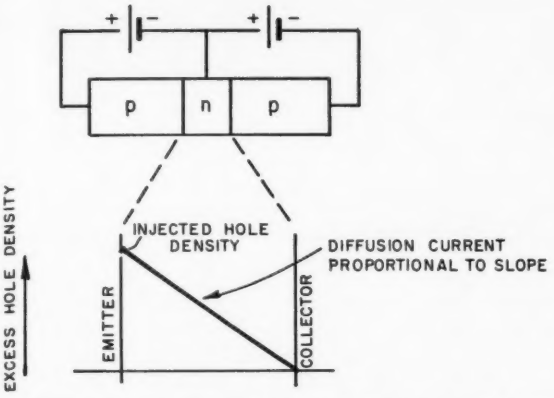

Figure 14. A p-n-p transistor and injected hole distribution in n-type base region.

sion length, and the smaller this spacing is relative to a diffusion length, the more efficient will be the transistor action.

Referring to Figure 14, the left hand junction or emitter is biased in the forward direction to inject holes into the middle or base region. Because this region is thin, most of these will reach the right-hand junction and only a small fraction is lost by recombination in the base. The right hand junction is biased in the reverse direction to collect the holes from the base region and transfer them to the right hand p-type region. Current flow through the base region is by diffusion along a concentration gradient as shown in Figure 14. This density distribution is maintained by the emitter injecting holes at the left junction and the collector sweeping them out at the right hand junction.

Since the forward conductance of a p-n junction is large, little power is required to inject hole current into the base region. On the other hand, the resistance of a reverse-biased junction is very high. Since the same current flows through the high resistance of the collector junction that was injected at the cost of very little power through the emitter, a considerably increased power may be developed in an external load.

In addition to the hole currents which form the basis of operation for a p-n-p transistor, electron currents also flow across the junctions as described earlier. In the p-n-p transistor these are unwanted currents and one of the problems of transistor design concerns the minimization of these currents.

Having discussed the basic considerations which make possible the bipolar transistor, it is now our intention to develop those factors which will express the limitations of the transistor, at least as it exists today.

Capacitive Effects in a P-N Junction

Two phenomena give rise to the flow of capacitive currents in a p-n position. The first of these is the junction or transition capacitance which is a consequence of the depletion of mobile charges near the junction as discussed earlier. Referring now to Figure 9, it is seen that a p-n junction may be viewed as two regions containing mobile charges separated by a thin non-conducting region from which the mobile charges have been depleted. This intervening region may be viewed somewhat as the dielectric of a conventional parallel plate condenser. Thus, the transition capacitance of a p-n junction depends on the thickness of this intervening region, the area of the junctions and the dielectric constant of the semiconductor. In a transistor, the transition capacitance of the collector junction is an important factor in determining the frequency response of the transistor.

As the reverse voltage applied to a p-n junction is increased additional mobile carriers will be swept out to leave a greater number of uncompensated fixed charges to support the increased voltage. Thus the thickness of the depletion layer increases and the capacitance decreases. This property of the capacitance of a p-n junction varying with the applied voltage has led to the development of special diodes to exploit this effect.[3]

The second phenomenon leading to the flow of capacitive currents in a p-n junction is a result of the nature of the minority carrier flow, i.e. a diffusion flow. We have seen that diffusion current flow is proportional to a charge density gradient (Figure 14). To increase the diffusion flow we must change this gradient. This is done by lowering the barrier so that the hole density is increased just in front of the emitter junction. This results in a change in the total charge contained in the base region and the change in total charge with applied voltage corresponds to a capacitance which is referred to as a diffusion capacitance. In a transistor, current is transferred through the base region by a diffusion flow and the resulting diffusion capacitance appearing at the emitter-base terminals is another important factor in determining the frequency response of a transistor.

Frequency Limitations and Improved Transistors

One additional physical element is needed to discuss the frequency limitations of the diffusion transistor. This additional element is the base-lead resistance. Its physical nature is illustrated by the section of the alloyed junction transistor of Figure 15. This resistance is predominantly the normal resistance of the semiconductor between the point of attachment of the base lead and the transistor junctions. Other transistor constructions have similar base-lead re-

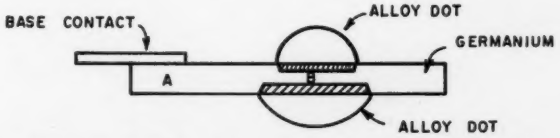

Figure 15. Section of alloyed junction transistor to illustrate origin of base lead resistance in the resistance of germanium between base contact (A) and transistor junctions (B).

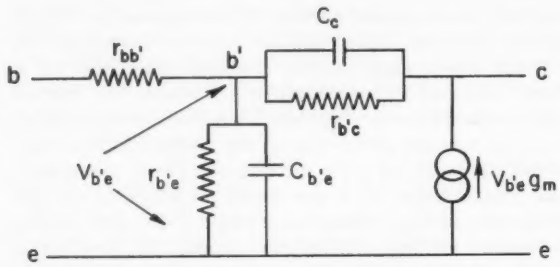

Figure 16. Equivalent circuit for common-emitter representation of the transistor.

sistances, although the detailed behavior may vary.

An equivalent circuit for the transistor can now be assembled from the physical elements that have been discussed. An equivalent circuit for the common-emitter connection, widely used in circuit applications, is shown in Figure 16. The base lead resistance discussed above is $r_{bb'}$ and b' denotes an internal base point. The current which crosses the emitter junction but is not transferred to the collector junction is accounted for by $r_{b'e}$. This current may be the unwanted (in a p-n-p transistor) electron current injected into the emitter, or may result from recombination of holes in the base region. The collector junction resistance, $r_{b'c}$ is, in principle, very high but practically is more often dominated by leakage currents across the collector junction. The current generator $g_m V_{b'e}$ in the collector circuit represents the injected current which has diffused across the base region. The capacitive elements are C_c, the transition capacitance of the collector junction, and $C_{b'e}$, the diffusion capacitance representing the change in charge stored in the base region which must be made to alter the diffusion current flow. At high frequencies the resistances in shunt with capacitive elements can be neglected so that the equivalent circuit reduces to that shown in Figure 17. It may be seen that there are two important time constants which determine the frequency response, one in the input circuit, $r_{bb'}C_{b'e}$, and one in the output circuit, C_c/g_m. A figure of merit for the high frequency performance may be taken as the reciprocal of the product of these time constants,[4]

$$\frac{g_m}{r_{bb'}\, C_{b'e}\, C_c}$$

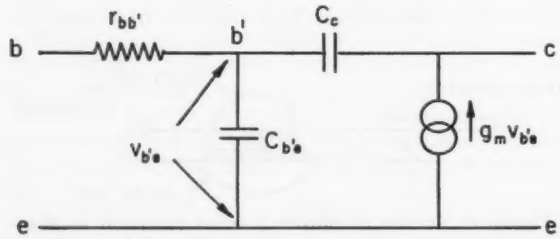

Figure 17. Equivalent circuit of a junction transistor at high frequencies.

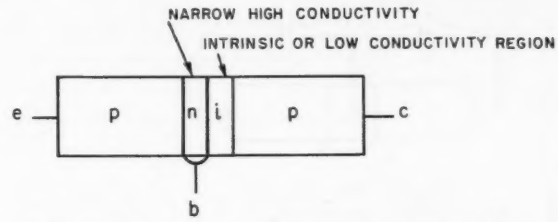

Figure 18. Schematic structure for a p-n-i-p transistor.

Indeed, this quantity is proportional to the square of the maximum frequency of oscillation. Since the transconductance, g_m, and the diffusion capacitance, $C_{b'e}$, are both concerned with the propagation of minority carriers across the base region, it turns out that the factor $g_m/C_{b'e}$ may be replaced by a "transit time," τ, for the minority carriers to cross the base region. The figure of merit is then

$$\frac{1}{r_{bb'}\, C_c\, \tau}$$

These factors will now be discussed with reference to actual transistor structures which have been utilized or proposed to extend the high frequency limits. The straight forward methods are evident. To reduce the base-lead resistance, the base region is made of high conductivity material and the geometry chosen to minimize the resistance to the base contact. To decrease collector capacitance the junction area is reduced and to reduce transit-time, the spacing, W, between emitter and collector junctions is reduced. Examples of this straight-forward approach are the high-frequency alloyed-junction transistor[5] and the surface-barrier transistor.[6]

The straight-forward approach is not without its compromises, for a higher base conductivity increases the collector capacitance, lowers the collector breakdown voltage and decreases the emitter injection efficiency. Some of these compromises are avoided in the p-n-i-p transistor structure[7] of Figure 18. Here a region of high resistivity (intrinsic) material is sandwiched between the n-type base region and the p-type collector region. The intrinsic region is one of relatively few mobile charges and the depletion region of the collector junction readily extends through this region. This gives a much thicker depletion region and hence a lower collector capaci-

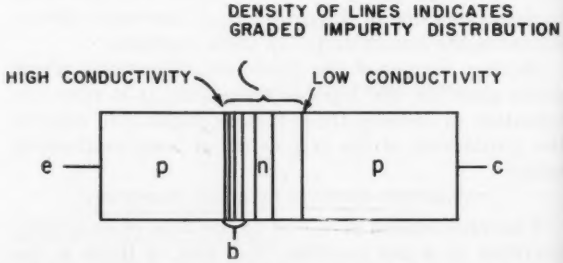

Figure 19. Schematic structure for a p-n-p graded impurity drift transistor.

tance. Further, the collector breakdown voltage is no longer diminished by heavily doping the base region to provide a reduced base-lead resistance. Transit-time considerations through the n-type base region are the same as for a diffusion transistor of the same base width.

The above construction accomplishes decreases in transit time by reduction of the width of the base region. Current flow through the base region is by diffusion as we have discussed above. In the "drift" transistor,[8] shown schematically in Figure 19, an internal electric field is built into the base region so that the injected carriers are transported across the base region in the manner of a drift current rather than by diffusion. One method of building into the base region the required drift field is to vary the impurity distribution so that the conductivity is high near the emitter and low (intrinsic) near the collector. Such a graded distribution of impurity atoms may be produced by solid-state diffusion at high temperatures. With such a non-uniform distribution, the electron density (in n-type base material, for example) is greatest in the highly doped region. These electrons would tend to diffuse out of the regions of high concentration but, in doing so, set up a restraining electric field due to the now uncompensated positive charge on the atom from which the electron originated. Thus, an internal electric field is set up to keep the electrons in the regions of high impurity concentrations. This behavior is quite similar to that discussed earlier for the restraining fields set up in a p-n junction. However, in the present case, the field is in such a direction to accelerate holes injected by the emitter towards the collector.

There are limitations to the drift field that can be built into the base region. Too high a conductivity under the emitter lowers the injection efficiency and may increase the emitter transition capacitance to where it becomes an important factor in limiting the frequency response. For germanium, it appears that a drift field may be built into the base region such that the carrier velocity is about four times the equivalent carrier velocity achieved with diffusion flow. Thus, the transit time may be reduced by a factor of four. In addition, the high conductivity required near the emitter satisfies the requirement for a low base-lead resistance, while the low conductivity required near the collector satisfies the requirements of a low collector capacitance and a high breakdown voltage. Thus, the overall frequency limit of the drift transistor may be of an order of magnitude greater than that of a comparable diffusion transistor.

A recent proposal[9] for a high-frequency transistor involving carrier motion in the high fields of a depletion region has been made. This is the "spacistor" transistor shown schematically in Figure 20. Two contacts are made to the transistor region of a p-n junction biased in the reverse direction. The left contact is an emitting contact and the right contact is a modulating contact which controls the injection

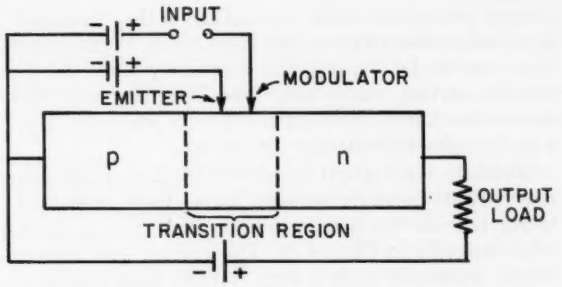

Figure 20. Schematic structure for a "spacistor."

of carriers by the emitter by varying the local space potential in the depletion region. That is, the modulating contact deforms the normal voltage distribution in the p-n region to control the number of carriers injected by the emitter. Since the field in a reverse biased junction may be very high (10^4 volts/cm), the injected carriers are rapidly swept away to reproduce the input signal in the output circuit.

It is of interest to compare the basic quantities affecting transist time for the conventional transistor, drift transistor and "spacistor" transistor. To do this, junction spacings will have to be assumed. For the conventional transistor a base width of 2×10^{-4} inches will be assumed. Transistors having a base width of 1×10^{-4} inches have been made.[10] For the "spacistor" transistor, a spacing of 10^{-3} inches will be assumed between the emitter and collector since it is difficult to see, at least with present geometries, how two physical contacts can be placed in a transition region in less space. It is also assumed that the field is 10^4 volts/cm in the depletion region. At these high fields, electron velocities no longer increase for further increases in the applied field. The comparison is shown in the following table:

Transistor	Electric Field* v/cm	Electron Velocity* cm/sec	Transit Time sec
Conventional	100	$.38 \times 10^6$	13.3×10^{-10}
Drift	400	1.5×10^6	3.3×10^{-10}
"Spacistor"	10,000	6×10^6	4.2×10^{-10}

* These are equivalent quantities in the case of the diffusion flow of the conventional transistor.

It appears from transit-time considerations alone, im-

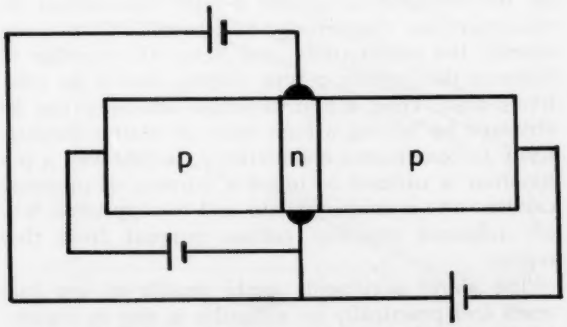

Figure 21. Schematic structure for a "tetrode" transistor.

proved geometries must be realized if the "spacistor" is to take advantage of the high fields in the depletion region. Of course, the frequency limit, as discussed earlier, must also take into account other factors but there are insufficient data presently available to make a frequency comparison.

Actually the highest transistor oscillation frequencies (1200 megacycles/sec) have been reported[10] using tetrode transistors whose structure is shown schematically in Figure 21. The tetrode is a conventional transistor with a very narrow base region required for high frequency operation, but has an additional base contact so that a base bias can be applied across the base. This biases off most of the emitter area and transistor operation occurs only in a very small area near one of the base leads. Thus, by electrical means, a very small active area is attained in contrast to other structures in which the area is that of the physical geometry. By this means the base-lead resistance and capacitances are very effectively reduced so that operation at high frequencies is attained.

EMITTER INJECTION EFFICIENCY AND HIGH CURRENT OPERATION

In the previous discussion it has been tacitly assumed that the properties of the emitter p-n junction could be adjusted so that the current across the emitter in a p-n-p transistor is carried predominantly by holes going into the n-region. However, in a p-n junction electrons are also injected into the p-region from the n-region. This current serves no useful purpose (in a p-n-p transistor) and reduces the desired injection efficiency. We have also seen that the injected currents of a p-n junction are proportional to the saturation currents so that it will suffice in discussing the proportion of current carried by holes or electrons to consider the factors determining the saturation currents. The hole saturation current, we noted, is proportional to the equilibrium hole density in the n-type base material and, analogously, the electron saturation current will be proportional to the electron density in the p-type emitter region. These minority carrier densities are inversely proportional to the majority carrier densities in each case. Thus, to increase the hole current one decreases the majority carrier density in the n-type material, i.e. the conductivity of the n-type base should be relatively low. Conversely, to decrease the electron current the conductivity, and hence the number of holes in the emitter p-type region, should be relatively high. Thus, a high injection efficiency can be obtained by having a high ratio of emitter conductivity to base region conductivity. In this way a p-n junction is utilized to inject a current of minority carriers into a semiconductor and to suppress a flow of undesired majority carrier current from that region.

The above arguments apply strictly at low currents and practically no difficulty is met in transistors designed for small signal applications. At high currents, where the injected carrier density approaches the carrier densities normally present, the injection efficiency of an emitter decreases because of a disproportionate increase in the unwanted component. This leads to distortion and loss of gain in transistor power amplifiers. The reason for this decrease in injection efficiency may be seen briefly as follows (for a p-n-p transistor): As large numbers of holes are injected into the base region, equivalent numbers of electrons also enter through the base contact to preserve electrical neutrality. At large currents this added electron density becomes comparable to the normal electron density. These electrons, as well as the ones normally there, tend to diffuse across the junction thus greatly increasing the electron current crossing the junction and reducing the efficiency of the junction as a hole emitter. The solution to these difficulties has been to increase the conductivity ratio between the emitter and base materials still further by the use of special emitter alloys.[11] Although this solution does not, in principle, eliminate a decrease in emitter efficiency at high currents, the emitter is so good that other effects (e.g. surface recombination) predominate in the operation of the transistor.

Another solution to the high current problem has been proposed[12] but not yet employed in commercial devices. This is an emitter junction of semiconductors having different bandgaps as shown in Figure 22. In this type of junction, the junction barrier height is different for holes and electrons. If the barrier for electrons is greater than that for holes, the hole injection efficiency will be very high even at high currents. Because of the exponential dependence on barrier height of the current flow across the junction, this effect can be very large even though the barrier to electrons is not much greater than that to holes.

TEMPERATURE EFFECTS

Of the many effects which changes in temperature may have on the operation of transistors, there are two of particular practical significance which will be discussed here. The first of these concerns the rapid increase in saturation current with temperature. In addition to the current injected by the emitter, the

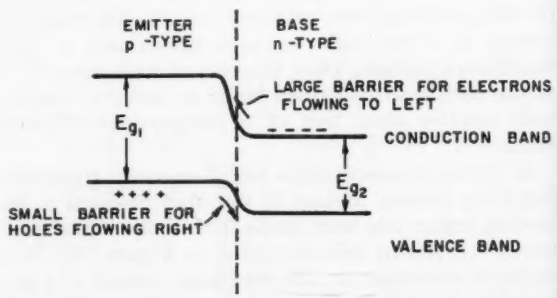

Figure 22. A wide-gap emitter junction where the bandgap (E_{g_1}) of the emitter material is greater than that (E_{g_2}) of the base material.

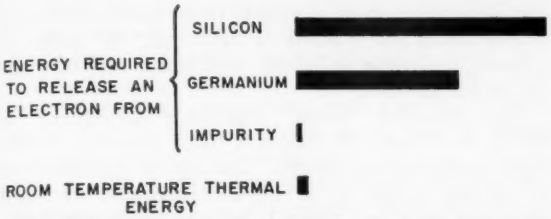

Figure 23. Energy required to release electrons from various atoms in a crystal.

transistor collector current includes the saturation current and hence is an undesirable current. The saturation current increases rapidly with temperature and can readily equal or exceed the useful transistor current. The transistor then becomes inoperative. Even before this point is reached, the efficiency of operation of the transistor in the current is impaired since a large part of the collector current is no longer controlled.

Earlier we pointed out that the charge-carriers responsible for the saturation current may be thought of as being obtained from the breaking of the crystal valence bonds. Thus, these currents are smaller in materials where a greater energy is required to break these bonds. The bar graph of Figure 23 shows, relative to thermal energy at room temperature, the energy required to release an electron from an impurity atom, from a germanium atom and from a silicon atom. It is seen that thermal energy is somewhat larger than that required to release an electron from an impurity atom. It is for this reason that at normal temperatures we can assume an electron from each impurity atom is available for conduction.

On the other hand normal thermal energies are much smaller than the energy required to extract an electron from either a germanium or silicon atom. Indeed, as was pointed out earlier, only about one electron per 10^{10} atoms (in pure germanium) is available to carry a current. Consequently, at room temperature, saturation currents are reasonably small but increase rapidly at a rate of about 10 per cent per Centigrade degree. See Figure 24. Because the energy required for bond-breaking is higher in silicon, the saturation currents are many times smaller in silicon transistors which are used where higher temperature operation is desired. It should be pointed out that although the currents are smaller in silicon, the variation with temperature is about the same percentage-wise as in germanium. However, since the currents are so much smaller this aspect of transistor operation is not affected until much higher temperatures are reached.

The other practical effect of temperature is closely related but is concerned with the forward current of a junction. In operation, a transistor is normally biased to provide a given current thus determining the "operating point." Now we earlier saw that the forward current of a p-n junction was proportional to the saturation current so that as the temperature is increased, the forward current will also increase shifting the operating point. A readjustment can be made by altering the bias voltage to accommodate the new conditions and this is often done in compensated circuits. The shift in voltage required for each degree change in temperature is, quite approximately, equal to the energy required to break a bond divided by the absolute temperature. This is about 2.3 x 10^{-3} volts/Centigrade degree for germanium and somewhat higher for silicon.

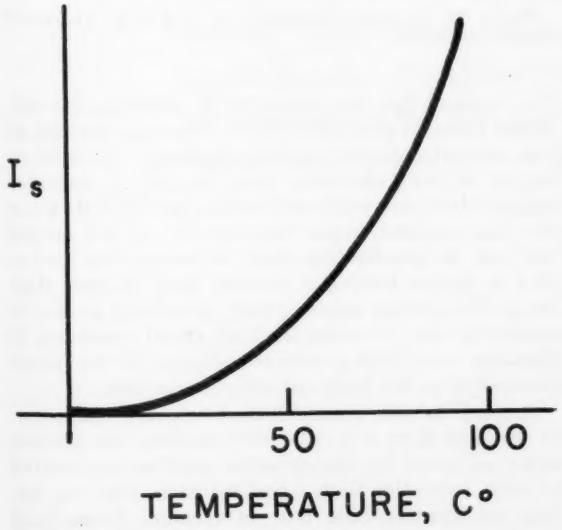

Figure 24. Variation of saturation current with temperature in germanium.

NEW TRANSISTOR MATERIALS

While transistors built from germanium are admirable devices at moderate frequencies and at

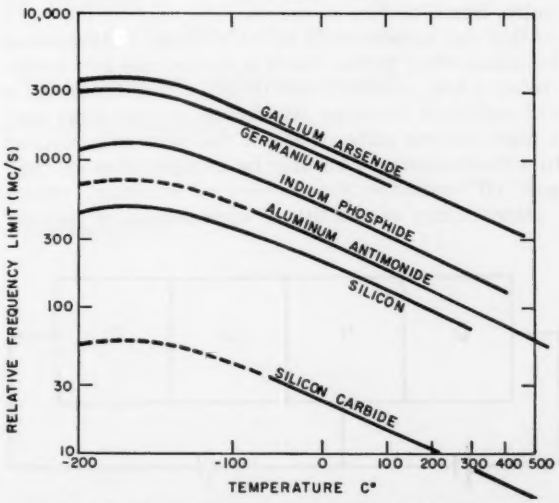

Figure 25. Relative frequency and temperature limits for various transistor materials.

moderate temperatures, many other semiconductors could be used. Some of these, it may be hoped, will enable us to alleviate some of the limitations discussed above. For example, the well-known advantage in the use of silicon is in extending transistor operation to higher temperatures, although with some sacrifice in frequency response. A large number of materials have been explored for potential transistor use and transistor action has been observed in quite a few. However, those presently appearing as most promising are relatively few in number. A current evaluation of the potential of these new materials compiled by D. A. Jenny of RCA Laboratories is shown in Figure 25. This figure shows the frequency *vs* temperature capabilities for various semiconductor materials relative to germanium. The frequency scale is set at 1000 megacycles at room temperature for a germanium transistor with a base thickness of 10^{-4} cm. The right hand end of each curve indicates the probable maximum temperature of operation extrapolated from the assumption of 100° C for germanium.

It is seen that gallium arsenide is the most promising material when both frequency and temperature are taken into account. Transistor action has been observed in this material and excellent gallium arsenide microwave diodes[13] have been made. For very high temperatures, silicon carbide appears promising but present mobilities indicate that its use in bipolar junction transistors will be limited to low-frequency devices.

POTENTIALLY BISTABLE JUNCTION DEVICES

In the conventional transistor discussed above the current collected at the collector is just slightly less than that emitted by the emitter. Such a transistor is said to have a current gain of approximately unity. There is another class of bipolar junction transistors in which the collector current can be greater than the emitter current, i.e. a current gain greater than unity. Some of this excess current may be fed back so that the device tends to "run away" until limited by some other factor. Such a device has two stable states, a low current state in which the feedback is not sufficient to cause the device to run away and a high current state in which the current is limited by a load resistor. This may be thought of as an "on" and "off" switch.

Since many of the future applications of transistors appear to be as elements in computer circuitry where much use is made of "on" and "off" states, it appears desirable to briefly mention a few of these transistor devices.

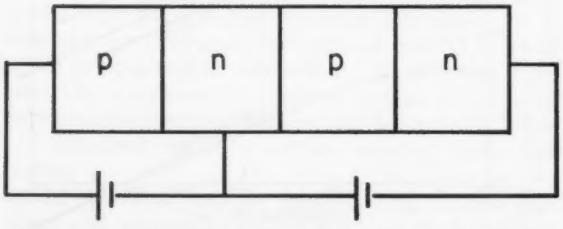

Figure 26. Schematic structure for a p-n-p-n hook transistor.

The so-called "hook" transistor structure[14] is shown in Figure 26. The left hand junction is forward biased as an emitter. The center n-p junction is reverse biased as a collector through the right hand p-n junction. Hence holes emitted by the emitter are collected into the second p-type region which is floating. As we saw earlier, a p-type region normally assumes a potential to retain holes so that these collected holes cannot pass into the right hand n-type region and are trapped in the p-type region. However, this accumulation of holes does lower the barrier to the right hand n-region letting some holes through but, more important, allowing many electrons to enter from the right hand n-region. These electrons are collected by the n-type base and flow out the base contact. Thus, the emission of holes from the left hand end region can control a greater current flowing in the right hand n-region giving a current gain greater than unity. As indicated above, in the proper circuitry, this transistor can then be used as a bistable device.

Bistable action can also be obtained in a recently announced device called the "Thyristor."[15] This is a p-n-p device with a special semiconductor contact made to the p-type collector region. See Figure 27.

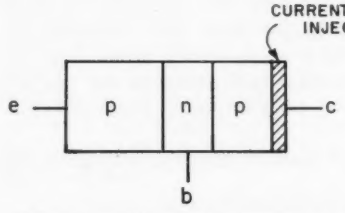

Figure 27. Schematic structure for a p-n-p "Thyristor" bistable transistor.

This contact has the property of allowing the collected holes to pass through in a normal manner at low currents. As the current is raised, however, it begins to emit electrons into the p-type collector region which are collected by the base and flow out the base contact. Again the current in the output lead can be greater than that in the emitter lead to give a device having a current gain greater than unity. This device appears very promising since it is relatively easy to make for high speed operation. It requires very little power to switch and the power dissipation in the high current state is low.

A third bistable device is the avalanche transistor. In the high field of a collector junction, the carriers being collected by the collector may be accelerated to such velocities that, upon collision with the lattice, an electron-hole pair is created. These may then be accelerated (in opposite directions) to create additional carriers. Thus, the original car-

rier may be multiplied many times in an avalanche process. Again the result is a greater current in the collector lead than in the emitter lead. Because of the high fields required in this device, the power dissipated when conducting high currents is quite high. Consequently, its outlook is less promising than the other bistable devices.

It should be mentioned that the point-contact transistor is also a bistable device. However, the disadvantages of the point-contact transistor have lead to its virtual disappearance from the transistor scene.

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Scientists of the Radio Corporation of America have experimentally developed a bi-stable, solid state, switching element which can also operate as a conventional high frequency transistor or in amplifying circuits. The device has been named the "Thyristor." The bi-stable performance characteristic enables the accomplishment with the Thyristor of switching functions which formerly required two transistors. A modified alloy-junction transistor, it is characterized by a good "On/Off" stability with high impedance in the "Off" position. It is capable of switching currents from one circuit to another in one fifty millionth of a second.

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WALTER T. WHITE & BERTRAM H. MANDELL

SPARROW I—EPOCH IN MISSILERY

ACKNOWLEDGEMENT

This article which was written by Walter T. White, Engineering Department Head for Missile Weapon System, and Bertram H. Mandell, Quality Control Manager, Surface Armament Division, Sperry Farragut Company, is published as of timely interest.

The Sperry SPARROW I, the nation's first air-to-air guided missile, is deployed with the Atlantic and Pacific Fleets. The missile is launched by carrier-based fighters and rides a radar beam to the target. SPARROW I has a cruciform configuration and includes a fuze, warhead, guidance and control section, power supplies and rocket motor.

The Sperry Farragut Company was established in 1951 to build and operate a plant for production of SPARROW I. Choosing the plant site, organizing and equipping the plant, selecting and training personnel, and establishing manufacturing operations were done to achieve proficiency in missile production. Comprehensive quality control and reliability engineering made possible the production of a thoroughly reliable missile. Success of the SPARROW I Weapon System has been substantiated by hundreds of air-to-air launchings.

INTRODUCTION

First air-to-air guided missile in the nation's arsenal, the SPERRY SPARROW I already had reached an advanced status before it was officially announced by the Department of Defense early in 1954. The announcement came after seven years of development by the Navy's Bureau of Aeronautics and Sperry Gyroscope Company. Admiral Arleigh Burke, Chief of Naval Operations, credited "years of intensive development by the Bureau of Aeronautics and Naval Air Missile Test Center, and Sperry for the readiness of the Fleet with this air-to-air missile system."

Commenting on the vastness of the technical subjects which had to be mastered in early guided missile development, Rear Admiral John E. Clark, Director of the Navy's Guided Missile Division, has said that "perhaps never in the history of human endeavor had man embarked on a program of such magnitude with so little to base his efforts on. . . . In ten short years, our scientists and engineers had produced guided missiles of amazing performance and reliability." A case in point, the SPARROW I program had to include, not only design, development and production of a "bird" consistent with the Navy's peculiar problems of shipboard use, but guidance and test equipments, training of ground and air crews, and the construction and operation of a plant specifically for missile production—all without precedents.

More than 100 prototype missiles had been constructed and critically test-flown between 1948 and 1951, including air launchings from Navy aircraft as early as 1949. Evolutionary models, these missiles were the forerunners of the production SPARROW I missiles now in service with the Sixth and Seventh Fleets of the U.S. Navy. Behind the initial, terse announcement of the first air-to-air missile system, is a pioneering project that began in 1946.

In December 1946, the Sperry Gyroscope Company was authorized to initiate a study program for the development of an air-to-air guided missile capable of intercepting bomber aircraft. Under this contract, with the Navy Bureau of Aeronautics, plans were made for wind tunnel test, simulator studies, development design, manufacture, and field testing of three progressively improved missile types: Test, Experimental, and Prototype.

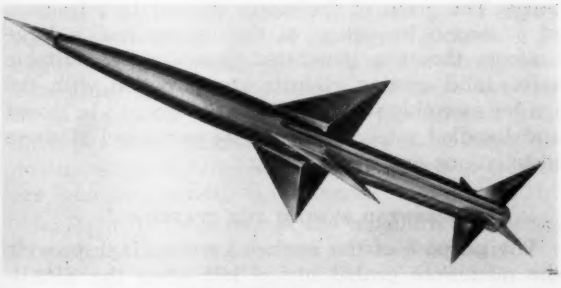
Also involved in this contract were preliminary

studies and resulting choice of the radar guidance system, missile guidance system, and missile aerodynamic configuration. The objective of the Sperry SPARROW I Weapon System was to defend carrier task forces from attack by enemy aircraft through the use of beam-riding guided missiles launched from carrier-based fighters. The probability of attack on Naval forces by high speed aircraft carrying guided missiles, as well as conventional armament, made necessary the development of this defensive weapon which is capable of relatively long range operation and which has exceptionally high single-shot probability of kill. The major operating elements of this weapon system are: (1) An aircraft carrier which serves as a mobile base and directs a fighter to the vicinity of the target; (2) the fighter squadron; (3) The missile carried by the fighter; (4) The fighter fire control system which indicates the course to be followed by the fighter; (5) The fighter radar set which transmits the beam which guides the missile, and which furnishes data to the fire control system for determining the course to be followed by the launching aircraft.

In additional to these operational elements, other items essential to system operation, such as test equipment, maintenance bases, logistical support, and personnel training programs, are parts of the SPARROW I Weapon System.

SPARROW I MISSILE

A major element of the Weapon System, the SPARROW I is a supersonic air-to-air, beam rider type of guided missile. The missile consists of a fuze and warhead, a source of hydraulic and electrical stored energy, a guidance system and a rocket motor, all packaged in an 8-inch diameter, 12½-foot cylindrical body with a pointed ogival nose. Four variable incidence wings are attached near the center of gravity and are deflected to maneuver the missile throughout its flight. Four fixed tail fins provide longitudinal stability. This arrangement of wings and tail fins is a cruciform configuration and provides for maneuverability in any direction without the necessity of banking the airframe for a turn, as with conventional aircraft. The assembled missile weighs about 300 pounds. Attachment lugs are located on the body to suspend the missile from the launching rack of the carrying aircraft.



SPARROW I missile.

ARMING THE FIGHTER

The SPARROW I is carried externally under the wings of fighter aircraft . The fighter is equipped with airborne guidance radar and is armed with four missiles. These are carried by launching racks attached to stub pylons. Typical installations are on the Douglas F3D-2M Skynight, the Chance-Vought F7U-3M Cutlass and the McDonnell F3H-2M Demon. These jet aircraft operate from both carriers and shore bases, and are effective at all operational altitudes against high-speed jet bombers, fighters, and certain missiles.

In tactical flight operations, enemy aircraft are picked up by the airborne radar and SPARROW I missiles are launched by the fighter and controlled by a guidance system that "looks through the clouds" and places the missile squarely on the target. Fighter aircraft armed with SPARROW I missiles are successful in attacks against high and low-altitude aircraft targets which are flying either singly or in groups.

GUIDANCE AND CONTROL SYSTEM FOR SPARROW I

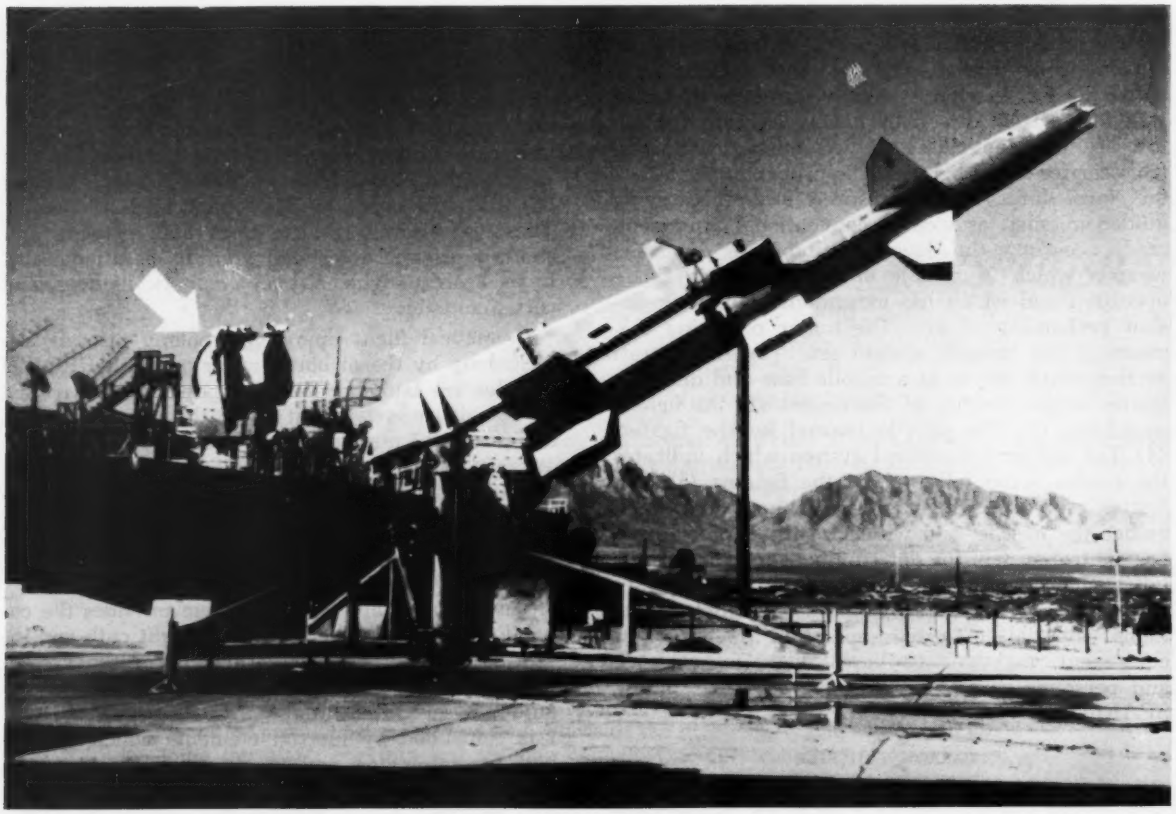
The guidance and control system provides the capability for the missile to alter its flight path and intercept an evasive target. Elements of the system function as the brains, nerves and muscles of the guided missile. The initial flight path for SPARROW I is controlled by inertial elements which include both accelerometers and gyroscopes. The later phase of flight for SPARROW I is controlled by beam signals and the missile follows the axis of the radar beam to the target.

The principal elements of the guidance and control system are:

a. Multi-axis gyroscopes and accelerometers.
b. Missile antenna and receiver for detecting the intelligence in the guidance beam.
c. Missile computing circuits to shape the signals to obtain precise and stable beam riding.
d. Servomechanisms for positioning the wings of the missile as required for maneuvering in flight.

These elements are packaged in a number of unitized separate assemblies in order to facilitate manufacture, test and field servicing. Both the mechanical and the electronic components are packaged to form complete functional assemblies. This greatly facilitates the preparation of specifications on a logical basis for each element, and it simplifies system checkout and maintenance for the missile.

The guidance and control section is an assembly of the foregoing components which is contained in the cylindrical body of the missile. The supporting structure is designed to provide for simple mechanical attachment of the elements, as well as convenient electrical interconnection of the units. Extensive flight tests have shown that the complete assembly is highly reliable under the rugged environmental conditions of missile launching and flight.



TALOS, the Navy's new long range surface-to-air missile, will be guided to its target by super-radars, developed and produced by Sperry Gyroscope Co. The radars, which use antennas resembling gigantic searchlights, are able to pick up targets many miles beyond human vision. The Navy recently disclosed that Sperry also is producing a similar radar system for guidance of Terrier missiles.

POWER SUPPLIES

The power supplies for SPARROW I include battery sources for electrical energy and a high-pressure hydraulic accumulator for the mechanical energy required to position the wings. Both supplies are designed with adequate capacity to furnish the energy required for the duration of the flight of the missile. Because the supplies provide power for the guidance and control system, the battery and the accumulator are packaged in the cylindrical section of the missile near the wing-positioning servomechanisms.

SPARROW I ROCKET MOTOR

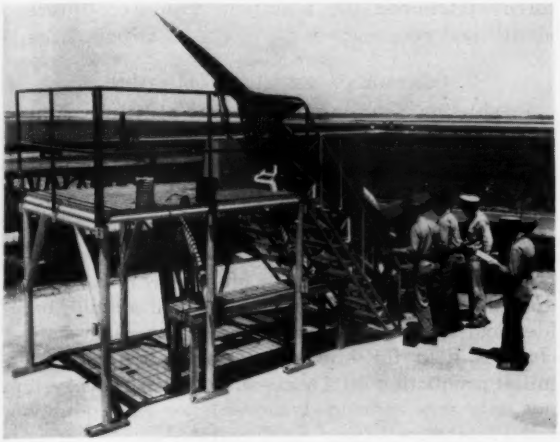
The rocket motor is the source of energy which provides the thrust that gives the missile the velocity increment over its launching speed. Thrust on the missile in the forward direction results from the reaction of the hot gases ejected at high velocity in a rearward direction. The hot gases are generated by the steady combustion of the high-energy fuel of the rocket motor.

The motor is packaged to form a smooth cylinder that is a section of the missile's body. It consists of three major components: namely, the case, the propellant grain, and the igniter assembly. The case is a thin-walled metal cylinder with an attachment mechanism to the forward section of the missile, and with a nozzle which directs the high-velocity gases aft. The high-energy propellant uses solid concentric grains with a plastic base which burn uniformly, and thereby gives a steady thrust to the missile. The chemical composition of the grain provides an oxidizing agent, and therefore burning rate essentially is independent of altitude.

The igniter assembly fits into the forward section of the motor and is triggered by an electrical impulse. The grain of the motor is fired in a fraction of a second by action of the igniter and a large uniform thrust is generated immediately. Suitable safety and arming circuits are provided with the igniter assembly so that the live motors can be stored and handled safely by ordnance personnel at shore installations and aboard ship.

WARHEAD SYSTEM FOR SPARROW I

The purpose of the warhead system is to provide the maximum probability of kill when the SPARROW I intercepts the target. The kill must be posi-



Arming SPARROW for ground launch.

tive and immediate in order to eliminate the possibility of a crippled enemy aircraft completing its bombing run before crashing into the sea. With this as an objective, a significant part of the missile's weight and volume is allocated to this payload.

The warhead assembly for SPARROW I includes three major elements; namely,

a. The safety and arming mechanism which provides positive safety of life for ground, shipboard and flight personnel under all conditions of environment and handling.
b. The fuze which detonates the warhead at target interception.
c. The warhead which includes an igniter and explosive assembly which when detonated will kill the target.

These elements are packaged in a section of the cylindrical body and form a separable assembly to facilitate manufacture, and to provide safe field handling and storage.

FLIGHT OF SPARROW I

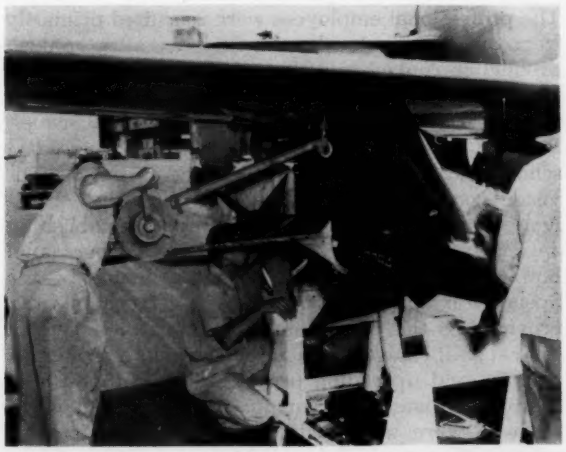
The SPARROW I missile is launched when the pilot of the fighter aircraft closes the firing switch. This action sends to the missile an electrical pulse which ignites the rocket motor. The resultant thrust propels the missile forward relative to the launching rack and the missile quickly attains a speed significantly greater than that of the carrying aircraft. By motor burnout, which occurs within seconds after launching, the missile's velocity is twice to three times the speed of sound. This is in excess of 1,500 miles per hour. When attacking an enemy target, the missile either is launched singly or several missiles are launched rapidly in sequence.

In flight, the missile has the capability of altering its path by deflecting control surfaces. Initially after launching, the trajectory of SPARROW I is controlled by inertial guidance. In the later phase of flight, the wings of the missile deflect in response to guidance signals from the radar beam which is pointed at the target. Accordingly, it is said that the missile "rides the beam," and SPARROW I is classified as a "beam rider" missile. Because the guidance beam is positioned precisely in the direction from the launching aircraft to the target, the missile is guided along a trajectory which leads to an interception even under evasive action. Destruction of the target is effected by the lethal action of the fuze and warhead when the missile intercepts the target. The accuracy and reliability of SPARROW I in flight has been proven by hundreds of instrumented launchings where precise observations were recorded.

PLANT FOR MISSILE MANUFACTURE

For the production of the SPARROW I missile, Sperry Farragut Company, Division of Sperry Rand Corporation, was organized in June 1951 to build, equip and operate a Naval Industrial Reserve Aircraft Plant for the Navy's Bureau of Aeronautics. The plant is located on 100 acres, four miles from Bristol, Tennessee, in the Holston Mountain Range of the Appalachians. Ground was broken in December of 1951 and a modern, well-equipped plant was built for production of missiles and guidance equipment.

The plant, constructed of concrete and steel with aluminum panel siding, consists of an enclosed factory, laboratory, service and office areas totaling 537,000 square feet. The factory is a single-story, windowless construction, while the office space is in a two-story administration building. These two structures are connected by a service bay which contains a completely equipped cafeteria. The plant is fully air-conditioned and includes an electrostatic air-filtering system. Ample parking area, a railroad siding, sewerage and industrial waste treatment fa-



SPARROW being hoisted in plane on starboard wing of F3D aircraft.

F3H-2 M with 4 SPARROW I missiles attached.

cilities, cooling tower, and an emergency water tank comprise supplemental facilities at the plant site.

The factory was laid out essentially on a production flow basis with raw materials and purchased parts received at one end of the factory floor and finished products shipped from the opposite end of the building. Neither automated nor conveyorized production means were employed in the manufacture of SPARROW I missiles, inasmuch as such means were not deemed suitable for the required production operations.

MEN FOR MISSILE MANUFACTURE

The Bristol, Tennessee-Virginia area is primarily agricultural in nature and did not, therefore, provide a ready-made pool of trained manpower for staffing the SPARROW I production operation. The management and key engineering personnel of the Company were supplied by the Sperry Gyroscope Company, Division of the Sperry Rand Corporation—that Division having developed the SPARROW I missile. The professional employees were recruited primarily from outside the local area. Shop, quality control, production control, and clerical personnel were, with few exceptions, local people who were trained for their jobs by voluntary, off-the-job extension schooling and on-the-job training. The local vocational school and University of Tennessee Extension Division cooperated wholeheartedly and most effectively with Sperry Farragut officials in establishing appropriate training courses for the local personnel both prior and subsequent to actual hiring by the Sperry Farragut Company. The Company, in turn, provided on-the-job training for many employees in critical skill categories in accordance with a planned training and upgrading program. The end result of the training was a harmonious team of skilled workers who were well qualified to fulfill their critical roles in the on-schedule production of high quality, reliable, SPARROW I guided missiles. This work force epitomized the ambition, initiative, interest, ability and cooperativeness of the local population.

CONTROL OF MISSILE PRODUCTION

Production planning and control at Sperry Farragut were keyed to an orderly system of drawing change control, and meticulous production progress reporting and follow-up. Required changes were classified as to urgency and only those which justified immediate action were introduced prior to a normal "block" point. Every effort was made to produce a discrete quantity, or "block," of missiles to an identical design configuration with non-critical changes held for implementation concurrent with initial production on a succeeding block. This system not only was a decided convenience in production, but greatly facilitated field maintenance. The production progress reporting system continuously indicated the actual status of all missile parts and assemblies with respect to required position on a "line-of-balance" chart. Unfavorable trends and lagging individual items were made immediately apparent by this system and were promptly singled out for special attention and corrective action.

MISSILE MANUFACTURE

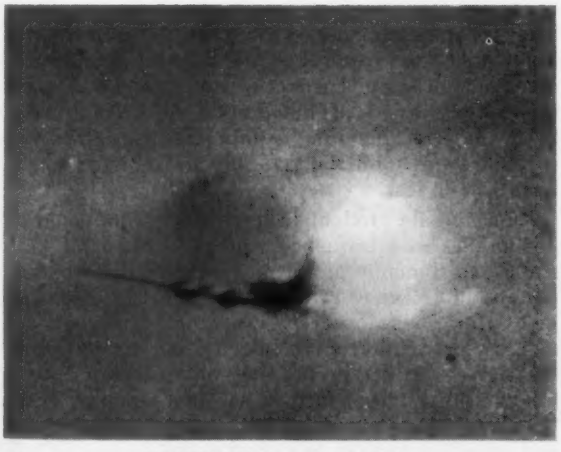
SPARROW I production by the Sperry Farragut Company, at Bristol, consisted of the manufacture, inclusive of factory test, of the complete guidance and control section, electrical and hydraulic power assemblies, and the airframe of the missile. The rocket motor, fuze and warhead, which comprised the balance of the missile configuration, were procured by the Navy directly from other prime contractors for eventual assembly to guidance and control, and power sections at Naval field installations or aboard ship.

Factory layout provided for a purchased material holding and checking area inside the plant, adjacent to the receiving platform. From this area, entire lots were routed to adjacent incoming material quality control stations for inspection and test. Completely equipped mechanical inspection, electrical test, and materials testing laboratories in the plant verified conformance of incoming material with purchase specifications. Subsequent to confirmation of acceptability, incoming raw material was color-coded for identification and routed to raw material stores. Similarly, acceptable purchased components were routed to finished parts stores.

The detail parts of the missile include not only commercially available items such as hardware, resistors, capacitors and tubes, but also many parts designed specifically for SPARROW I. Accordingly, the machine tools and production equipment in the plant were devoted largely to the manufacture of the special detail parts. The fabrication of these parts involved machining of castings and forgings, turning, and sheet metal work.

To facilitate operations on the major categories of

SPARROW I warhead shot against B-17 drone.



SPARROW I warhead shot.

SPARROW I missile leaves F3D.

machining work, two principal machining areas were established. These were designated, respectively, as the "casting line" and the "turning line." Essentially two process shops, these "lines" were tooled to facilitate all machining operations peculiar to their type of work. The casting line, for instance, received raw, purchased, stress-relieved, aluminum-alloy die castings and performed all required grinding, milling, drilling, and tapping operations, to produce finished parts from these castings. The turning line received rod and bar stock and produced finished turned parts. Both lines fed intermediate machined and finished items to separate, completely equipped heat-treating, and painting and plating areas, for such operations of these types as were required. The sheet metal shop handled the relatively small volume of punch press and sheet metal extrusion work required for missile parts.

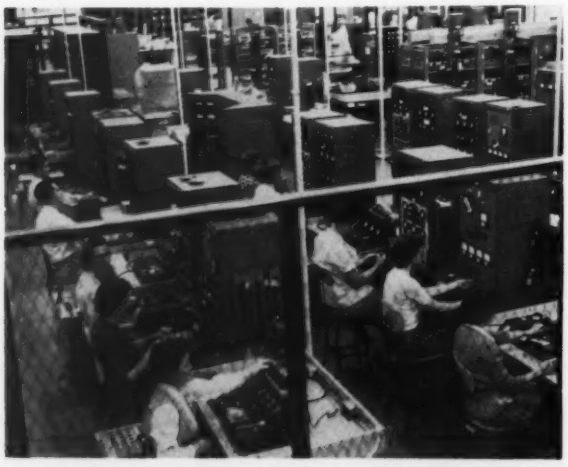
Airframe shells were machined in a special area that was tooled to handle the relatively larger aluminum and magnesium castings and extrusions from which the control and hydraulic power sections of the airframe were fabricated.

Although the majority of transformers required for the missile were sub-contracted to capable manufacturers in this field, a critical group of transformers was manufactured in the plant, as were all required special coils and gyroscope stators.

The tool room was equipped to handle the manufacture, modification and maintenance of the special tooling.

ASSEMBLY, INSPECTION AND TEST

Purchased and manufactured detail parts were released from stores to the assembly lines and areas in quantities and types compatible with the block of missiles to be manufactured. Manual assembly lines and areas were established for distinctive types of work; i.e., electrical assembly, wire preparation, transformers and coils, assembly of gyroscopes and hydraulic assembly. Within the electrical assembly area, separate lines were established for the production of individual units, such as servo amplifiers and guidance amplifiers. Required parts for these assemblies were stocked at appropriate points in the line for convenience of assemblers. Pertinent inspection and test operations were conducted at stations strategically located in the line.



Sperry Farragut electron tube testing.

Environmental test laboratory, Sperry Farragut altitude and humidity chamber.

Gyroscopic and hydraulic assembly, inspection, and test operations were conducted in "super-clean" enclosed areas established exclusively for such work. Within these areas, special precautions were taken to safeguard assemblies from contamination by dust and other foreign particles. These measures included pre-assembly ultrasonic cleaning of parts, and the wearing of lint-free garments by all persons working in or visiting the areas. Similar precautions were employed in connection with ball-bearing inspection activities.

Final missile assembly was effectively keyed to the receipt of components from the respective lines and areas. To this extent, all component assembly lines served as "feeders" for the final missile assembly line and components were stocked at the latter line rather than in a separate storeroom. Under this arrangement, only "hardware" items were fed to the final missile assembly line from a stockroom. Overhead materials-handling equipment was employed to facilitate final missile assembly and delivery to and from system test.

Final missile production testing was conducted on all missiles in a sequence which provided for both static and dynamic performance checks before, during and after exposure to simulated firing shock and flight vibration. Moreover, several missiles from each month's production were selected by BuAer representatives for comprehensive environmental tests following the initial factory acceptance tests. These "samples" were subjected to altitude, temperature, and vibration tests in the plant's environmental lab-

oratory and acceptability of the month's production quota was conditional upon satisfactory performance of these representative sample missiles. Additionally, missiles were selected each month for air launching at the Naval Air Missile Test Center and achievement of a specified high reliability and accuracy was a further condition of final acceptance of production output.

MISSILE RELIABILITY AND QUALITY CONTROL

Missile reliability engineering and production quality control efforts were closely coordinated to provide an effective system of factory and field failure reporting and analysis. Punched-card and automatic data processing techniques were used to maximum advantage in this work and served to reveal promptly the nature of failure trends.

The successful conduct of quality control and reliability programs required a prompt, efficient, and uniform means of reporting failures as they occurred both in the factory and in the field. It was essential that such reporting be uniform, to permit direct integration and comparison of field and factory failures.

The outstanding characteristic of the failure reporting system was its ability to promptly present, for the benefit of all concerned, both general and specific information concerning reliability trends—i.e., product failures by stage of test, field or factory location, units affected, specific component responsible, and exact nature of the defect.

Inasmuch as data processing equipment ideally suited the requirements of the reporting system, maximum use was made of the capabilities of such equipment. The failure card, on which required entries were posted by cognizant factory and field service personnel, was designed to facilitate rapid key punching of all information posted thereon by the Plant's Tabulating Department—to which all such cards were directed.

Prompt accumulation and analysis of failure information produced by tab runs, its effective presentation to Engineering and Production Management, and systematic follow-up to confirm corrective action, were the basic responsibilities of the Plant's Quality Control and Engineering Reliability Departments.

Once alerted to the existence of a significant failure trend, it was Management's responsibility to confirm and implement the required corrective action.

Carefully planned laboratory tests were then employed to establish failure causes and, subsequently, to prove adequacy of proposed corrective action. The Reliability Engineering Section, which reported directly to the Chief Engineer, was responsible for approving all proposed missile design changes, as well as analyzing and reporting on field test and firing results. This section maintained close liaison with the Company's field engineering organization as well as with the production quality control group.

The quality control policies and practices employed in the production of SPARROW I missiles directly reflected management's keen awareness of the quality requirements which are essential in the production of reliable guided missiles. While acknowledging that quality had to be built into the product, and could not be inspected or tested into it, Sperry management recognized that the costs associated with intensive inspection and test could be more than offset by elimination of rework costs and latent reliability problems which result from failure to detect discrepant components prior to assembly. Accordingly, and in recognition of the severe environmental conditions and unusually high reliability requirements in a guided missile, purchased functional components, such as potentionmeters, resistors, capacitors, and relays, were 100% tested to specifications before acceptance for product use. Electron tubes were 100% microscopically and electrically tested before and after a combined burn-in and vibration cycle. Acceptance sampling plans were *not* employed for functional components. Discrepancies relating to purchased material were reported immediately to the purchasing department for initiation of corrective action by responsible vendors. Periodic summary reports of vendor quality performance were supplied to all operating departments by Quality Control.

To insure uniform and efficient checking for conformance with specifications, all inspection and test operations were performed in accordance with detailed check lists and procedures. Inspection of electronic assemblies for proper soldering and other workmanship attributes was performed at frequent intervals during fabrication. Final inspection of assemblies was conducted on a 200% basis with additional auditing checks by inspection supervision for the purpose of rating inspectors periodically on their proficiency. Continuous direct liaison between inspection and manufacturing supervision, as well as weekly summary reports, assured prompt action to correct below standard workmanship trends. Frequent meetings, attended by management personnel, were scheduled for the purpose of discussing quality control, reliability, design and production problems. Responsibility for initiation and follow-through of all corrective action was confirmed at these meetings and progress was regularly reported until a satisfactory solution had been reached with each particular problem. Committees were employed whenever it was expeditious to conduct joint departmental investigations of problems. Committee reports and recommendations were evaluated at the management level and confirmation of final action required in connection with committee conclusions stemmed from this level.

Continuous emphasis to all plant personnel was placed on the Company's quality control objectives by the use of posters and supplemental literature throughout the plant and by prominently displayed process average charts in the manufacturing areas.

CONCLUSIONS

The SPARROW I marks an epoch in missilery. The system represents a major accomplishment in guided missiles by the U. S. Navy and Sperry. Significant steps in the program include conception and design of the missile and its guidance system, prototype missile manufacture and successful flight test, construction and operation of a plant specifically for missile production, and Service evaluation and acceptance of the production SPARROW I Weapon System.

The major objectives of the project have been to achieve an effective weapon system with an accurate and reliable missile designed to be manufactured at reasonable costs on a schedule which meets Navy requirements. As a result of the achievements on this program, the U. S. Navy's supersonic SPARROW I air-to-air guided missile system is now in a combat-ready status. Squadrons of the Navy's operational jet interceptors armed with the missiles are deployed on carriers in both Atlantic and Pacific Fleets. Other SPARROW I missiles are operational with all-weather squadrons of the U.S. Marines at shore bases. The Sperry SPARROW I now is on guard day and night around the world for Naval fleet units and shore installations.

United States Navy and Marine pilots have demonstrated the high reliability and deadly accuracy of the Sperry SPARROW I Weapon System by hundreds of missile launchings against target drones. The lethal warhead has blasted out of the sky all types of targets including high-speed jet aircraft and missiles.

The SPARROW I guided missile system is undoubtedly the most versatile weapon used for arming Naval aircraft. Previously, attacking enemy aircraft might have escaped detection by operating under conditions of poor visibility or by cloud screening. Now, the SPARROW I guidance system can aim the missile directly at the target in spite of the inability of the pilot "to see"; destruction of the enemy aircraft by the lethal warhead is assured. Versatility of the SPARROW I Weapon System has been proven by effective attacks against high and low-altitude targets flying either singly or in groups.

The present readiness of the fleet with this highly reliable and effective air-to-air missile system results from years of intensive development by the Navy's Bureau of Aeronautics and Air Missile Test Center, and the Sperry Gyroscope Company. The delivery of SPARROW I missiles in production quantities to fill the magazines of aircraft carriers with this "new type of ammunition" is a result of proficient plant operation with exceptional quality control at the Sperry Farragut Company. This competent human effort directed by the National Defense authorities has produced a weapon that is a powerful deterrent against a surprise attack by enemy aircraft.

In a staff article, "Missiles and Rockets" editors recently discussed the organization of the Soviet Space Agency. The top planning group is said to be the Commission on Astronautics of the Academy of Sciences, composed of a group of top scientists. This group evolves the program, identifies and assigns research tasks, and coordinates efforts. Design, production, logistics and launching are the function of the Army. The Commission is reported to have been established early in 1955.

—from "Missiles and Rockets"
December 1957

"TRANS. INST. OF MARINE ENGINEERS"

TRAINING OF ENGINEER OFFICERS AND NAVAL CONSTRUCTORS IN THE ROYAL NAVY

ACKNOWLEDGEMENT

This reprint consists of two of the five papers presented at a symposium on "The Education and Training of Naval Architects and Marine Engineers," before a joint meeting of The Institution of Naval Architects and The Institute of Marine Engineers on 6 February 1957. The papers were published in the September 1957 edition of the "Transactions of the Institute of Marine Engineers." The author of Part I is Captain I. G. Aylen, Assistant Engineer-in-Chief (Personnel), Admiralty; the author of Part II is S. J. Palmer, Royal Corps of Naval Constructors, Professor of Naval Architecture, R. N. College, Greenwich.

I—TRAINING OF ENGINEER OFFICERS

INTRODUCTION

THIS paper is being presented at a time of particular interest and importance to the future of the Royal Navy owing to certain far-reaching changes in the officer structure which were announced last year. The Service is, therefore, in a transition period between the old and new schemes of training and this fact somewhat complicates the task of making a presentation on the subject. The broad principles, however, remain, and the professional standards will not in any way be altered.

The requirement is for an officer who has received full professional training, and been given the opportunity early in his career to obtain a knowledge of all sides of ship life, technical and human, so that he may later be able to play a larger part in the higher administration of the Service.

It is first necessary to examine the changes in the officer structure to see how they affect the duties for which officers are being trained.

CHANGE IN OFFICER STRUCTURE

These changes are required to compete with the revolutionary advances in ships, weapons, and aircraft. They are directed towards the ultimate improvement of the career prospects of all specializations, and in particular towards making full use of the expericene and knowledge of more senior officers of the engineering, electrical, and supply specializations, who it was felt could play a more important part in the higher administration of the future Navy, given the chance of more experience in the junior ranks outside their special technical fields. This, indeed, accords with the trend of industry in this country.

Any cadet now entering the Navy does so as "an officer"—which is his prime function, and his early training is, to the greatest possible extent, common (except at present for the electrical specialization) whether he is eventually to become a seaman, engineer, or supply specialist. After later training for his specialization, every junior officer will, so far as his specialist duties permit, take part in the day to day duties of running a ship in harbor or a shore establishment. In the same way, however, as only a qualified aviator can command an aircraft, whatever the seniority of his passengers, so only a seaman specialist will be appointed to command seagoing ships. But for other normal working command problems, all cadet-entered officers of the four specializations are now included in a single list, known

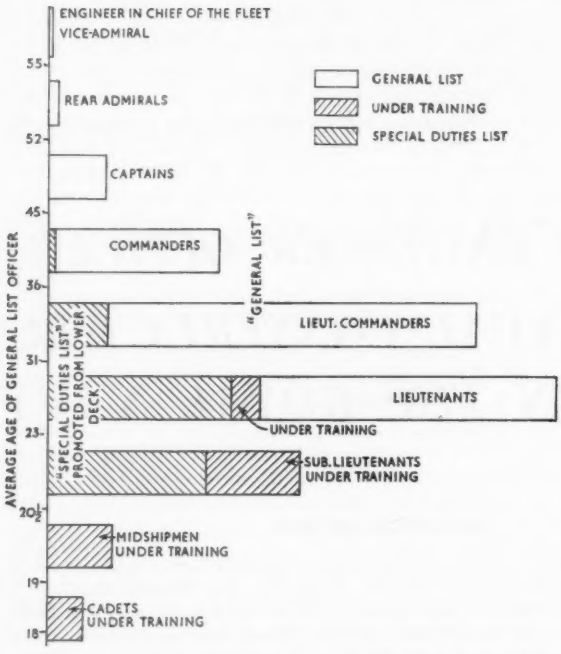


Figure 1. "General List" and "Special Duties List" officers of the engineering specialization.

as the "General List" and will be placed on a similar footing. In fact, in the close confines of a modern warship, the interdependence in action of one department and another must be such that officers and ratings are "all of one company."

At the same time it is intended that improved careers should be offered to those promoted from the lower deck, whose undoubted specialized practical experience has proved invaluable through two world wars. Such officers, formerly known as Warrant and latterly Branch Officers, are now included in the "Special Duties List," with titles Engineer, Sub-Lieutenant, Engineer Commander, etc. (their sub-specialization being denoted by a suffix M/E, A/E, or O/E, which is explained later). They are generally interchangeable within their own sub-specialization with the General List officers in the lower ranks. There are in addition a few exceptional ratings called Upper Yardmen who have been selected at an early stage for promotion to the "General List." Figure 1 shows the relative numbers of officers of the engineering specialization at present in each rank, and the relationship between the "General" and "Special Duties" lists.

Substantial changes of this nature will take some years to implement fully, but they will be progressive and indeed have already started to take place.

NATURE OF DUTIES

The engineering specialization is at present split broadly into three, marine engineers (M/E), air engineers (A/E), and ordnance engineers (O/E), with a fairly free interchange in the higher ranks. On the material side the marine engineer sub-specialist deals mainly with the propulsion and the associated auxiliary services of ships, submarines, and coastal craft; the air engineer deals with aircraft, airframes, and engines and he may be a qualified pilot; the ordnance engineer deals with gunnery equipment, torpedoes, and guided missiles. All are responsible for their own personnel in the performance of their technical duties.

Figure 2 shows the approximate distribution of duties in the various ranks of the "General List," with which this paper mainly deals.

It will be seen that a good deal of the time up to the rank of Commander is spent afloat (or, for air engineer officers on air stations), initially in a watch-keeping or junior capacity, and latterly in entire charge of main propulsion and auxiliary machinery or of mechanical maintenance of aircraft, or of weapons, together with all associated personnel.

As an example H.M.S. *Eagle* (152,000 shp) carries the engineer officers shown in Table I.

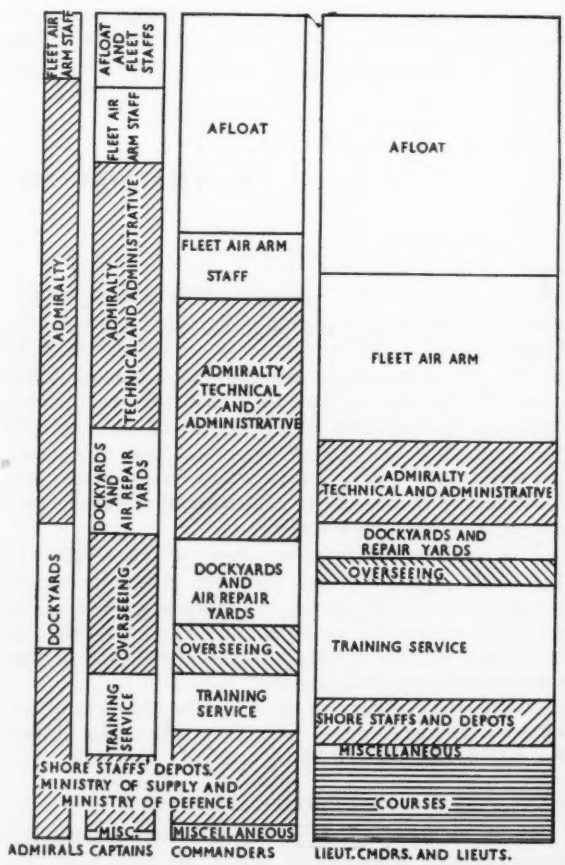


Figure 2. Present nature of duties of "General List" engineer officers.

TABLE I

	Cdr.	Lt.-Cdr.	Lt. or S/L	Under Training	Total	Duty
M/E	1	3	14	7	25	Main and auxiliary machinery. Flight deck machinery. Damage control
A/E	1	2	5	1	9	Maintenance of aircraft squadrons
O/E		1	1	1	3	Maintenance of weapons

A *Daring* class destroyer carries as engineer specialists one commander and one lieutenant for the main and auxiliary machinery and one lieutenant for weapon maintenance.

A "T" class submarine carries one lieutenant or sub-lieutenant.

In sea-going appointments any of the commanders and below may be "General List" or "Special Duties List."

The most senior sea-going appointment is that of a Fleet Engineer Officer who is generally of captain's rank, serving on the staff of a Commander-in-Chief.

Dockyards and Air Repair Yards

Each Royal Dockyard, which may deal with the entire modernization of a carrier and the major repairs to all classes of ship, has a rear admiral or captain as the Manager of the Engineering Department, with a staff of specialist officers. There may be as many as 4,500 civilian employees under his control, even under peace-time conditions, and his job is comparable with that of managing director of a large industrial firm. Similarly, the air repair yards under a captain of the engineering specialization deal with repairs, modernizations, and conversions of naval aircraft, and employ civilian labor forces of up to 1,500 men. The Flag Officer Reserve Aircraft commands three air stations and three air repair yards, and he, the Chief Ordnance Engineer Officer, and the Assistant Director of Dockyards are rear admirals of the "E" specialization.

Training

From Figure 2 can be seen the heavy load carried by the specialization, assisted by the highly qualified Instructor Officers, in training its own officers and technical ratings. At any time there are some 3,000 personnel under training, from the age of 15 onwards. Of all tasks it is perhaps one of the most exacting and the most rewarding. All engineering training establishments are commanded by an officer of the "E" specialization.

Technical Administration

The majority of these posts are in the Admiralty Departments of the Engineer-in-Chief, Director of Naval Ordnance, Director of Dockyards, Director of Underwater Weapons Material, Director of Aircraft Maintenance and Repair, and the Ministry of Supply; the functions of these departments are generally to translate the requirements of the Naval Staff into technical terms, to guide the various contractors to produce these requirements in the desired form, and to ascertain by shore and sea trials that the equipment functions correctly. Subsequently they must ensure, by a carefully planned maintenance program, that all such equipment is ready for immediate use in war. It is natural therefore that in these departments many of the more able technical brains of the specialization will be found. It must be emphasized strongly here that the function of these departments and the engineer officers in them is not to design but rather to guide the designers and to criticize design proposals. They are enabled to do this by virture of a higher standard of professional training allied to wide technical user experience obtained at sea. There is but little scope for the purely "back-room boy," since his place (and a very important place it is) is properly in research work or industry where his specialized talent can be drawn on as required, and since the continuity required for this type of work is incompatible with the wide experience necessary for a naval officer in the higher ranks.

General Administration

Under this heading come a variety of important tasks, not necessarily purely technical, such as the Admiralty staffs dealing with engineering personnel whose function is to advise the Second Sea Lord on the correct training and employment of officers and men of the technical specialization—Commanders-in-Chief's staff engineer offiers, and officers appointed for intelligence duties, naval attachés, N.A.T.O. staffs, and so on.

It can be seen that a great variety of professional tasks may fall to a naval engineer officer. He may well find himself as the engineer officer of a solitary destroyer patroling off Japan, then two years later training apprentices in Scotland, followed by taking charge of steam catapult trials in a new carrier. Or as a more senior officer he may be overseeing Admiralty gunnery contracts in the Midlands, followed by two years as the Fleet Engineer Officer in the Mediterranean and then in command of a training establishment of 1,000 young ratings. In general most appointments average two years, certain more specialized ones lasting three or four.

Ultimately he may rise to be Engineer-in-Chief of the Fleet, with the rank of vice-admiral; under the "General List" concept, an officer of the engineering specialization will on his merits be able to rise higher than vice-admiral and play an even more im-

portant part in higher administration; but at whatever age he retires it can never be said that his life has lacked variety.

Woven through all these duties runs the vital thread of the leadership of men. He can never hope to command the loyal respect of the men under him (be they sailors, scientists, or Chinese dockyard workmen), unless he has been brought up to think in terms of human relationships. A knowledge and understanding of mankind is just as essential as professional ability, whether he is in charge as a junior officer of a small party of men cleaning boilers, or as a senior officer in discussion with a leader of industry. Be he technically a paragon, his own personal character is of equal importance.

Probably no other walk of life may involve such high degrees of responsibility—responsibility sometimes of life and death—at such a young age. A submarine commanding officer in wartime may be as young as 22, and his engineer officer about the same. The engineer officer of a fleet carrier with machinery costing £3,000,000 may well be under forty. In many appointments the entire responsibility for welfare, discipline, and efficiency of many hundreds of men may rest with a technical officer—for whom technical training alone cannot be enough.

BROAD TRAINING IN FUNDAMENTALS

It can be seen from the above background that it is an obvious requirement for the naval engineer officer to be trained as broadly as possible. Mr. Love, in a recent paper,[1] used a quotation from Milton: "I call therefore a complete and generous education that which fits a man to perform justly, skilfully, and magnanimously all the offices both private and public of peace and war," which, if "all the offices" is taken to mean the many varied duties described above, fits the naval aim most aptly. It is essential that the early training in fundamentals as a mechanical engineer is not allowed to be obscured by a welter of practical detail. The technical complexities of modern warships and aircraft are indeed so great that the young officer could readily become ensnared in a web of such detail, which in any case may well be out of date by the time he meets it. The mechanics of solids and fluids, the laws of thermodynamics and electricity, the nature of material and mathematical treatment do not change, whatever form of propulsion may be in vogue at the time, be it steam, gas turbine or nuclear, above, on, or below the seas. Without an understanding of such fundamental principles, coupled with training in *how* to think, or without the inculcation of creativeness and judgment, or without a knowledge of the humanities, the education will not be "complete and generous."

Professor Christopherson has given his opinion[2] that the standard of certain University examinations had risen by about one year for each fifteen that passed. This is probably true in most sciences, and certainly in relation to the technological advances in the Services. In eighty years a guided missile is replacing a muzzle-loading gun. Consequently the trend towards specialization becomes more and more compelling, but, if the senior technical officer is to play an increasing part in the general administration of the Navy, it must be resisted. "If his general experience and ability to take a broad view are proven, he will stay. If he takes a narrow technical view he will not. In addition there will always be scope for the brilliant engineer who can carve a niche for himself, enjoying the advantages of being his own master, but running the risk of mental loneliness which can afflict men at the top." [3] It is the general experience and ability to take the broad view on which the conception of the "General List" of naval officers depends.

At the same time, the principle that all engineer officers should sub-specialize in marine, air, or ordnance engineering is being retained, since it is not thought practicable for a young man to master the details of construction, operations, and maintenance of all three and to practice them effectively. Given a broad training in the fundamentals of mechanical engineering, with a sound grounding in one aspect of the whole profession, and his general naval experience, it is hoped to produce a man who can perform "all the offices."

TRAINING AND ENTRY

Figure 3 shows the relative sources from which regular engineering officers are drawn.

The cadet and scholarship entries are drawn from all types of school; at the moment it happens that independent schools are providing the majority, but it is felt that there are many of the best boys from maintained grammar schools who are not coming forward as candidates.

For the scholarship entry and cadet entry, G.C.E. "A" level exemption by 2 "A" level passes (with 3 "O" level) has been only recently introduced, and may become increasingly popular with schools.

The pattern of training of engineer offices to suit these requirements can now be considered in four parts:—

(*a*) Early general naval training on the Britannia Royal Naval College, Dartmouth, to give the schoolboy a sound background for his naval career.

(*b*) Sea training in the fleet.

(*c*) Professional engineering training ashore in the Royal Naval Engineering College, H.M.S. *Thunderer*.

(*d*) Advanced engineering training (for a few selected officers) at R.N. College, Greenwich.

BRITANNIA ROYAL NAVAL COLLEGE, DARTMOUTH

It would be hard to find anywhere in this country an environment better suited for any young officer

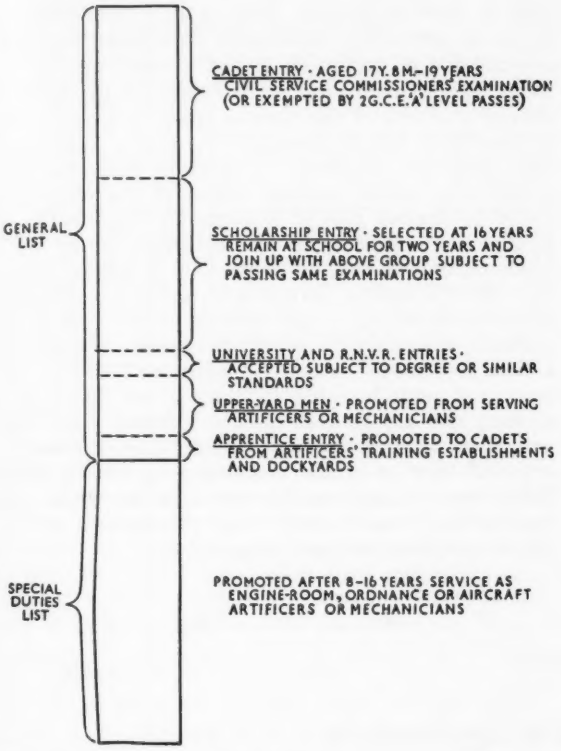

CADET ENTRY · AGED 17Y. 8M.–19 YEARS
CIVIL SERVICE COMMISSIONERS' EXAMINATION
(OR EXEMPTED BY 2G.C.E. 'A' LEVEL PASSES)
GENERAL LIST
SCHOLARSHIP ENTRY · SELECTED AT 16 YEARS
REMAIN AT SCHOOL FOR TWO YEARS AND
JOIN UP WITH ABOVE GROUP SUBJECT TO
PASSING SAME EXAMINATIONS
UNIVERSITY AND R.N.V.R. ENTRIES ·
ACCEPTED SUBJECT TO DEGREE OR SIMILAR
STANDARDS
UPPER-YARD MEN · PROMOTED FROM SERVING
ARTIFICERS OR MECHANICIANS
APPRENTICE ENTRY · PROMOTED TO CADETS
FROM ARTIFICERS' TRAINING ESTABLISHMENTS
AND DOCKYARDS
SPECIAL DUTIES LIST
PROMOTED AFTER 8–16 YEARS SERVICE AS
ENGINE-ROOM, ORDNANCE OR AIRCRAFT
ARTIFICERS OR MECHANICIANS

Figure 3. Sources from which engineering specialists are drawn.

to start his naval career than the B.R.N.C., Dartmouth. The setting, the amenities and, above all, the tradition of the college which has supplied so many of our great naval leaders in the past make it one of the most treasured possessions of the Service. But those who knew it of old will find great changes. It is no longer a school for bringing up thirteen-year-olds to manhood in a naval atmosphere; it is now an adult establishment, greatly enlarged, with Sandhurst and Cranwell as its counterparts; with its combined naval and civilian staff the atmosphere is attuned to the new requirements.

A proportion of the officers under training are from old and new Commonwealth nations; all receive exactly the same training as officers of the Royal Navy.

First Period

For the first two terms the aim is to inculcate in all cadets a general naval knowledge and discipline, and with the wide diversity of academic attainments of cadets on entry, to ensure an adequate scientific and mathematical background and an ability to express themselves clearly in writing and speech. Some engineering is taught to all cadets, so that when they go to sea in their third term they can understand the principal items of the ships' machinery.

Sea Training from Dartmouth

The sea training is carried out in a squadron of three modern frigates and two minesweepers attached to the college specifically for the purpose, and affords general familiarization with all subordinate duties. Cadets live and work under exactly the same conditions as naval ratings, the aim being to acquaint them with the ship's routine as it affects the sailor and conditions on the lower deck.

A short air course is also undertaken in this period.

Specialization

For the first year cadets will have been trained as officers unallocated to any specialization. After this they will become either seamen, engineer, or supply specialists according to their aptitude and, as far as possible, their preference, due account being taken of visual fitness and the need to have a fair share of talent in all specializations. (Arrangements for the electrical branch are still under consideration.)

Last Period

In the last period of four terms at the college, as a midshipman, training continues on a nearly common basis, the aim being to teach the professional and technical principles which a young officer must grasp before going to the fleet, thus forming a nucleus around which the practical knowledge to be acquired while at sea can accumulate. He should by then be an efficient and intelligent understudy to a qualified ship's officer.

The distribution of subjects covered in this period is shown in Figure 4. There is a slightly increased emphasis on mathematics, science, and mechanics for engineering specialists, while the seaman specialist covers more ground in navigation and com-

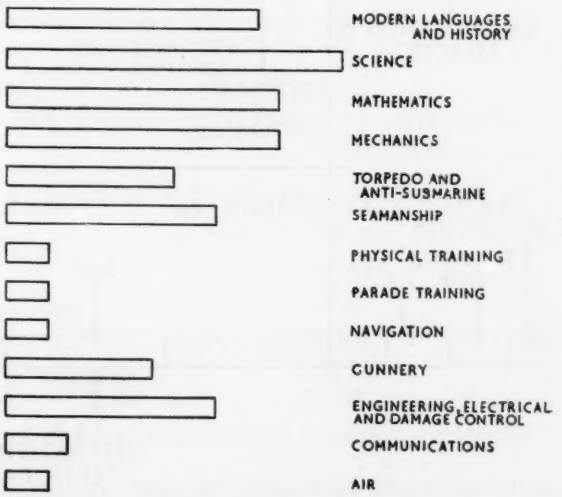


Figure 4. Distribution of subjects in last period (four terms) at the Britannia R.N. College, Dartmouth.

munications. Otherwise the syllabus is common for these two specializations.

It is at Dartmouth that the young officers' character will largely be developed. Great emphasis is placed throughout on getting to know the elements in small boats, on expeditions of an enterprising nature, and on a study of the humanities. This aspect will be referred to later.

SEA TRAINING IN THE FLEET

On leaving Dartmouth, seamen, engineer, and supply officers will go to sea in the fleet as acting sub-lieutenants for a period of some eighteen months. This will be their first real contact with ships and naval ratings apart from the term in the training squadron, and it is a vital period. They will be required to obtain a "Certificate of Competency" to cover general experience in all departments of the ship, understudying on the bridge, in the supply and electrical and weapon organizations, and in the machinery spaces. The engineering specialists will devote the last twelve months to the engineering side of their profession. They will be required to obtain progressively certificates signifying that they are capable of taking charge of a steaming boiler-room, watchkeeping on all varieties of auxiliaries, charge of a unit of the main engines, and finally an Engine-Room Watchkeeping Certificate, signifying that they are qualified to perform the practical duties of a junior engineer officer of the watch. It could be argued that it is anomalous to award an Engine-Room Watchkeeping Certificate before professional engineering training. This is not so, since the officer's earlier Dartmouth training will have covered the practical side to some extent, and there is much advantage in practical experience forming a first side to the training "sandwich." It may be compared with learning to drive a car before absorbing the mechanical details. Officers learn the principles of operation and maintenance of machinery, and become versed in lighting up and shutting down routines and rapid power changes while maneuvering. They emerge from the school atmosphere and learn to take responsibility.

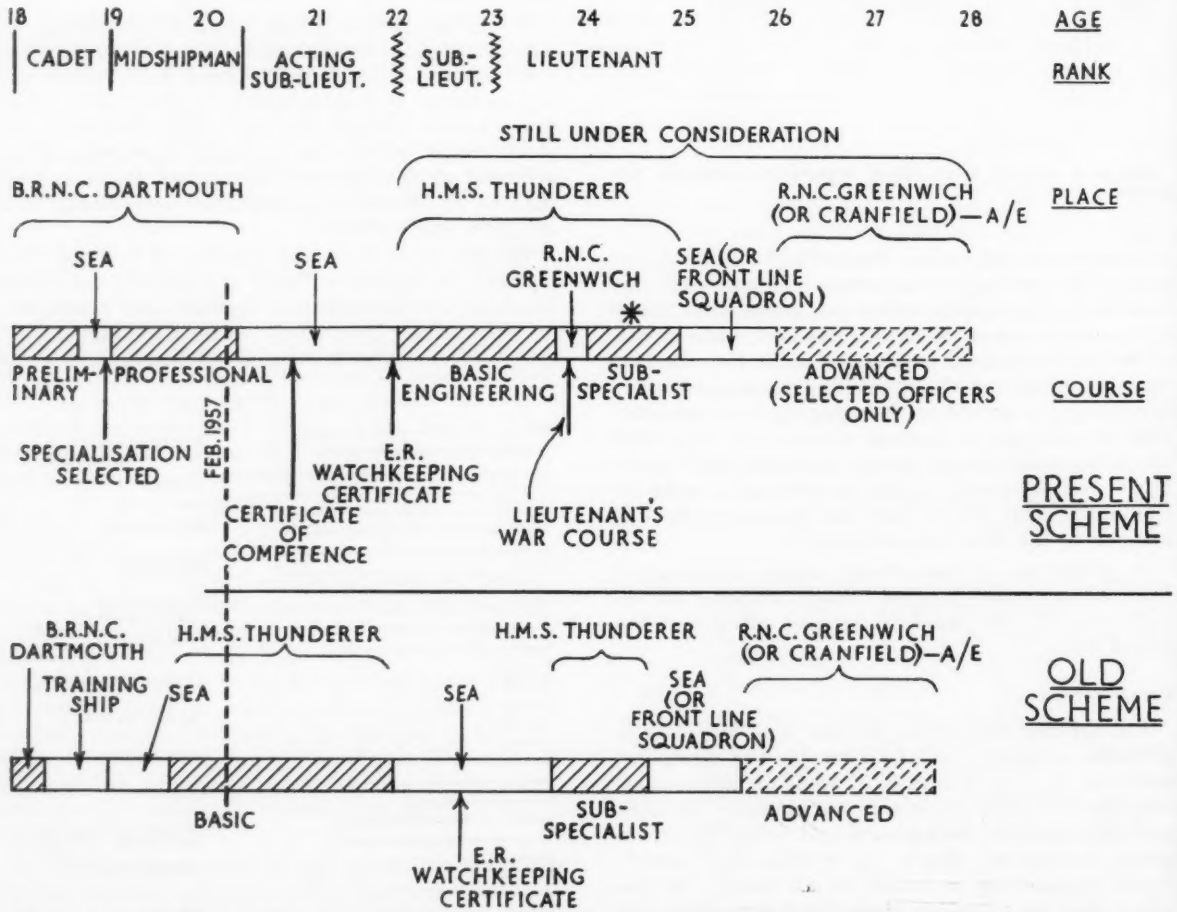


Figure 5. *O/E Sub-specialist's course is four terms, including periods at H.M.S. "Excellent" (gunnery and guided weapons) and H.M.S. "Vernon" (torpedo and anti-submarine).

PROFESSIONAL TRAINING

At this point it is necessary to depart from discussing the present scheme of training, because the final pattern of future professional training has still to be determined. The transition is now taking place —the old scheme is still running with some years' worth still in the "pipe line." Figure 5 illustrates the old and the possible development of the present scheme. The old scheme will, therefore, be described, since it will not finally die out until 1961, and the new final product will not differ greatly *technically* from the old, the aim being to enhance the present high professional standards of "General List" engineer officers.

H.M.S. "Thunderer"

Professional training is carried out mainly at the R. N. Engineering College, Manadon, near Devonport, which is an independent command known as H.M.S. *Thunderer*, and is the Alma Mater of the engineering specialization. The facilities afforded in H.M.S. *Thunderer* have been fully described elsewhere.[4] Suffice to say that it offers, with its extensive workshops, laboratories, demonstration rooms, hangars, test shops and playing fields in its 100-acre site, as fine a training for mechanical engineering as any in the country. The final stages to make it virtually self-contained have been started with the building of an extensive accommodation block, the foundation stone of which was laid by the First Sea Lord in July 1956. On completion, the old R.N.E.C. at Keyham, which has trained engineer officers almost without a break since 1880, will be taken over for other purposes.

The total officer complement at present is about 60 staff with 360 officers under training.

Professional training falls into two main phases, a common basic course covering 7 terms (2⅓ years), at the end of which the sub-specialization in marine, air, or ordnance engineering is selected, followed later by a sub-specialist course of 3 terms (or 4 terms for ordnance engineers). Between these two courses 5 terms are spent at sea in the fleet (which under the newer scheme will have already been served before joining H.M.S. *Thunderer*—see Figure 5).

Basic Course

This course was evolved in consultation with university and other authorities to provide a sound grounding in mathematical and mechanical sciences, to aim to teach *how* to think, to develop a broad understanding and sense of judgment, and provide the requisite background of knowledge for later courses.

Study during working hours is divided into lectures, practical laboratory work, workshop practice and technique, and tutorials. All officers require a number of hours of private study each week according to their ability, to keep abreast of the syllabus. Failure at progress examinations entails back-classing and special coaching in weak subjects.

The distribution of academic subjects taken is shown approximately in Figure 6. In 7 terms of 14 weeks each, the pace in which is intensive, some 2,360 hours' instruction is given, which is a little less than that given at London University and technical colleges—but further instruction in the later sub-specialist course, especially in chemistry, metallurgy, and design subjects brings this total to about the same.

Mention has previously been made of Upper Yardmen promoted from the lower deck on passing a stiff educational examination and the Admiralty Interview Board. They phase into the last four terms of this basic course, and thereafter are indistinguishable from their contemporaries.

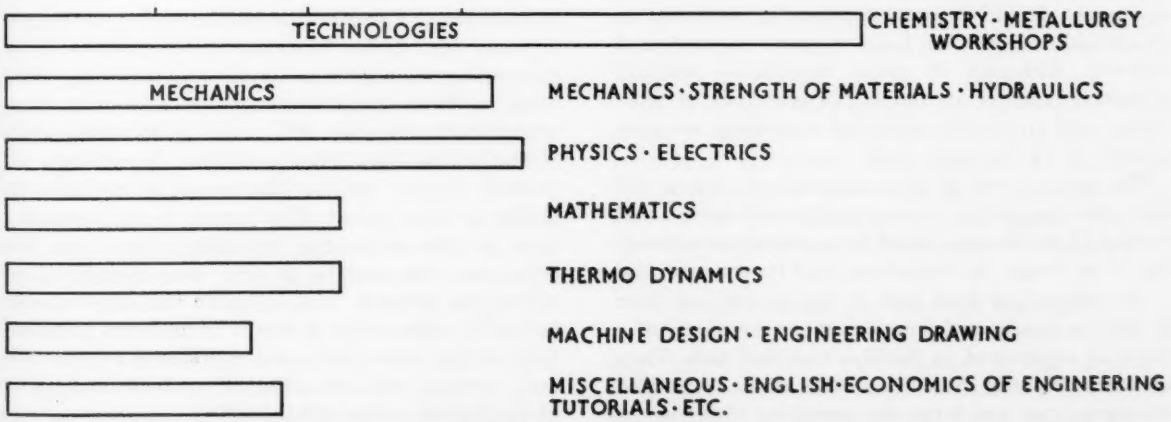


Figure 6. Distribution of subjects in basic course H.M.S. "Thunderer" (7 terms of 4 weeks—33 periods (55 minutes/week)).

Standards

It has always been the policy of the Engineer-in-Chief of the Fleet that all cadet-entered engineer officers must be trained to professional standards generally recognized in the country. Without such a background they will not be able to talk on level terms with their colleagues in industry, nor indeed to carry out the many varied duties which will later be their lot. The final examinations of the basic course are therefore keyed to those set by the Institution of Mechanical Engineers. All papers are set by examiners from Cambridge, London, or other universities or the Royal Naval College, Greenwich, to satisfy these minimum standards. Those who fail the progress or the final examinations at a second attempt are withdrawn from the Service. It follows that after the further requisite practical experience, all officers qualifying are later eligible for associate membership of the Institution of Mechanical Engineers if they wish it, being exempted from the qualfying examination for graduate membership by virtue of passing the Admiralty examination. They are similarly exempted for admission to the Institute of Marine Engineers or the Royal Aeronautical Society, as appropriate, and are also eligible for associate-membership in The Institution of Naval Architects.

Nearly all academic and laboratory instruction is given by serving officers of the Instructor specialization (most of whom possess First or Second Class Honors degrees) or fellow engineer officers. With a 2-3 year tenure of staff appointment, a degree of continuity as well as a "feed-in" of recent sea or air experience is assured.

Sub-Specialist Courses

After the period of sea training mentioned above, about 50 per cent and 30 per cent undertake the marine and air engineering three-term course respectively, and about 20 per cent the four-term ordnance engineering course. These courses are more practical than academic, although principles of machinery are learned rather than details of individual equipment. It will be noticed from Figure 6 that an appreciable amount of time is spent on electrical subjects. Although of major importance for the ordnance engineer specialist, the principles of electronics and automatic control of machinery are now considered as the tools of all.

The general aim of these courses is to equip officers with the ability to maintain overall operational control of machinery, based on a sound understanding of its design, its limitations, and its construction.

An interesting final task in the course has been to give to small syndicates broad requirements of a piece of equipment to fulfill a specified task. They are then required to devise, design, make completed drawings, cast and forge the necessary components, carry out all machining processes, and finally test the finished equipment to meet the required specifications. A cost analysis and a sales brochure is prepared, as if intended for production. The variations in approach have proved most illuminating, and valuable experience of the proper perspective of design and development has been gained.

During these courses some practical experience is gained in running under test conditions auxiliary machinery likely to be met in the Service. The air engineer officers have the use of a Bolton and Paul "Balliol" and an Airspeed "Oxford" aircraft at a nearby airfield as "flying test shops." (Those selected and who volunteer may later qualify as front-line pilots, and may ultimately become maintenance or Empire Test Pilots.) The ordnance engineer officers spend part of their course at other specialist schools learning the intricacies of guided weapons, conventional gunnery, and torpedoes.

At the end of these courses officers are generally considered fitted to go to the fleet or air stations in a junior complement billet, carrying with it definite responsibilites. It is impressed on them that learning is a continuous process, and all their former training has been directed towards enabling them to learn for themselves thereafter.

The advent of a small ship fleet has brought with it considerable accommodation problems. There is now little room to carry officers or men under training at sea—and however much one may wish to carry round supernumeraries for training, it is only possible to a limited extent. Every man must go to sea ready to assume a responsible job.

Leadership Training

At this point it is appropriate to mention one of the most important aspects of the training of engineer officers—indeed of all officers—not only in the Navy but in all the Services where man himself is the vital factor. This is the training in leadership. The problem is not entirely analogous to that obtaining in industry, where employers and employees do not live together, and where a man can usually give up his job at short notice to seek a better one. Nevertheless, industry has considered it necessary to make vast strides in caring for the well-being of its employees, and great pains are taken by most firms to foster loyalty which can only stem from contentment in the job under wise leadership, stemming, in turn, from confidence based both on mutual respect and on the superior professional ability of the leader. How much more necessary must be this leadership in a ship, where men are living for long periods at very close quarters, and where the ultimate trial in battle can only be successfully achieved as a result of ordered preparation, perfect discipline, and confidence in the officers; nothing will be achieved without leadership of the highest order at all levels.

There can be no formal way of developing leader-

ship—it cannot readily be taught in a classroom or from a book, since the prime requirements are those which should develop naturally in an early background in which the value of Christianity and human relationships are constantly stressed, coupled with self-confidence, readiness to take responsibility, initiative, and courage.

Discipline is comparatively easily instilled; the normal formal parades and physical training instill in addition a high degree of self-confidence in the young officers placed in charge. Ability to take responsibility is not so easy to inculcate in what is normally a well-regulated shore establishment, nevertheless the out of working hours organization of 360 junior officers in H.M.S. *Thunderer*, some of them Asian and foreign, allows a good deal of scope, and towards the end of their training period officers under instruction are in entire charge of everything which happens in the establishment out of working hours, as well as all the normal extra-mural activities common to a university. It is naturally these officers who set the tone and standards of behavior for the more junior officers.

Some 60 or 70 periods during the course are devoted to the pure mechanics of being a divisional officer in charge of ratings, every aspect possible being covered. Each officer spends one week as an assistant to a divisional officer for Engineering Mechanics in H.M.S. *Raleigh*.

One important innovation has recently been made. In their early terms all officers spend at least one week-end (including a night) on Dartmoor, regardless of weather, with some definite organized objective. The members of the third term then themselves organize an expedition to Scotland, usually to the Cairngorms or Glencoe, where the most rigorous conditions of ice and snow are sought, and set tasks are performed in groups of two or three. In their last terms they organize further expeditions on Dartmoor in charge of small bodies of Naval Apprentices or Engineering Mechanics.

Officers qualifying as skippers are encouraged to take the college yachts across the Channel during the leave periods, and have been very successful in the Royal Ocean Racing Club races.

The value of such character training is untold, in increasing self-confidence in learning to plan ahead, and in stimulating the will to endure by presenting the opportunities of developing capacity to face hazards, hardships, and difficulties.

Lastly, opportunity is taken to present lectures and talks on subjects of current interest outside naval affairs; every attempt being made to interest officers in such vital subjects as "the Christian answer to Communism." Perhaps it would not be indulging in heroics in the presence of organizations so predominantly maritime as the Institute of Marine Engineers and The Institution of Naval Architects to quote from John Buchan [5]:—

> The sea has formed the English character, and the essential England is to be found in those who follow it. From blue waters they have learned mercifulness and a certain spacious tolerance for what does not affect their craft, but they have also learned in the grimmest schools, precision and resolution. The sea endures no makeshifts. If a thing is not exactly right, it will be vastly wrong. Discipline, courage . . . and contempt for all that is pretentious and insincere are the teaching of the ocean and the elements, and they have been qualities in all ages of the British sailor.

The final aim is to produce a young officer who as well as being technically sound (and certainly occasionally capable of improvising makeshifts!) is essentially balanced in outlook, and able to measure up to the high words of praise given by John Buchan to the seafaring community of Britain.

ADVANCED COURSES

After one to two years' sea experience about 10 to 15 officers yearly are selected as a result of their performance at H.M.S. *Thunderer* and at sea, to undergo two-year advanced courses at the Royal Naval College, Greenwich (or at the College of Aeronautics at Cranfield in the case of air engineer officers). Their ages range from 24 to 27 at the start of the course. They are indicated in the Navy List by a dagger against their names, and hence are known as "Dagger" officers.

The aim of the advanced engineering course is to equip officers for leadership in research, development, and design which in later life they will be required to initiate, administer, and criticize. While they will not actually execute designs themselves, they will need experience of design work coupled with judgment and a broad background, including acquaintance with industry.

Hence the scope of the course is similar to that of an honors degree with additional emphasis on design methods, particularly towards an analytical approach to varied problems.

Advanced teaching in subjects such as mathematics, applied mechanics, physics, and chemistry is given by a civilian professional staff, while serving engineer officers give instruction in design work and related subjects and administer the course as a whole.

Close contact with industry is fostered by visits to firms engaged in current Admiralty work and by lectures at the college from members of the firms and organizations concerned. It is appropriate to record here the Admiralty's great appreciation of the very willing help that is given by industry in this way.

Installation design for warships' machinery is a prominent feature of the second year work. This is done in conjunction with students of the naval architecture department, future members of the Royal Corps of Naval Constructors. Many of the Royal Corps of Naval Constructors have already spent a

year living in H.M.S. *Thunderer* while studying in the constructors' training office at H.M. Dockyard, Devonport, before going on to Greenwich, and thus the early acquaintance of these two closely coupled branches of the service is fostered into co-operation.

The ordnance engineers study advanced gunnery techniques and guided weapons, while the air engineer officers study advanced aeronautical engineering design and production problems at Cranfield.

COMPARISON WITH THE UNITED STATES NAVY

It may be of interest to compare the system in force in the United States Navy.

It is considered that all officers must have a sound technical background, All regular officers undergo a four-year graduation course at Annapolis (or other civilian university) of which about half, therefore, is devoted to mechanical engineering.

They then proceed to sea as "Line Officers," and may undertake any junior duty on board, from the bridge to the engineroom. After two to three years, those interested in mechanical matters apply for a course at the Massachusetts Institute of Technology: those who qualify become engineering duty officers (E.D.) and, with few exceptions, after reaching the rank of lieutenant-commander are employed in the Bureau of Ships, shipyards, in laboratories, or overseeing. The posts of engineer officer of most ships and all commands at sea are filled by "Line Officers," who normally will not have had formal technical training beyond that at Annapolis; they will have had wide technical experience of all parts of a ship from the radar to the turbines and their specialized technical staff may consist largely of officers promoted from enlisted men.

It is noted that this scheme denies to the E.D. above the rank of lieutenant practical experience of administering a machinery installation and the handling of technical ratings at sea. Recently an E.D. has, however, for the first time been appointed as engineer officer of a fleet aircraft carrier.

The "E.D." is indistinguishable from the "Line Officer," and, according to a vice-admiral in the U.S. Navy, "he can only be recognized by the slightly more erudite expression on his face." He may be a dual "constructor-engineer" specialist. (The ordnance and air specializations are quite separate.)

The U.S. Navy scheme is somewhat similar to our own "Selborne-Fisher" scheme of 1902, whereby all except a very few selected (E) officers were interchangeable in any duty, command or technical. (For political and other reasons the scheme died in the Royal Navy after the 1914-18 war.)

COMPARISON WITH THE GERMAN NAVY

It is of interest that the new German Navy has quite independently evolved a scheme for officer training not unlike our own. Its main features include entry to a common list and common training for the first three years, including 4 months' training under sail and 3½ months' workshop training for all.

SPECIAL DUTIES LIST OFFICERS

From Figure 1 it can be seen that these officers comprise over 25 per cent of total strength of the engineering specialization. They are promoted as a result of a professional and educational examination and on their personal qualities. Their considerable practical experience at sea and in air stations is of the greatest value, and they are regarded as a most important mainstay of the Navy.

On promotion to officers they also are trained at H.M.S. *Thunderer,* where they play a very full part in the life of the college. Their six-months' course in their own specialization brings them in close contact with their contemporaries on the "General List," broadens their somewhat limited technical knowledge, and enables them to acclimatize themselves to their new role. Thereafter they are generally interchangable with their "General List" equals in rank, for most appointments of practical nature, but because they have not had the advantage of the wider earlier academic training, and are older, their career is limited.

Due to their proved services, it is intended that a still greater proportion of "Special Duties List" officers will be borne.

THE PAST AND THE FUTURE

How has the training in the past stood up to the requirements of the Service, and of the country as a whole? Although it is axiomatic that the technical standard of a Service cannot rise superior to that of the industry upon which it depends, the use to which the achievements of industry are put in development and design for the Navy is the responsibility of its technical officers. Under the guidance of naval engineer officers some conspicuously successful projects have been carried through—the mirror sight for deck landing on carriers, the Deltic lightweight diesel, the steam catapult now in use in the United States Navy and the Royal Navy, and the lightweight Y.100 steam installation for new frigates, to mention a few: and in the gas turbine world the *Grey Goose* was the first ship to be driven solely by gas turbines. There are many other examples in the ordnance and air worlds. Their success shows that the early training and experience of the officers concerned enabled them to make contributions in their own spheres towards the engineering and general industry of the country, on which the life of the Navy depends. And perhaps the results of two world wars have been appreciably affected by the role of the Navy, including its technical officers.

In 1828 the First Lord of the Admiralty, Lord

Melville, wrote: "Their Lordships feel it their bounden duty upon national and professional grounds to discourage to the utmost of their ability the employment of steam vessels as they consider the introduction of steam is calculated to strike a fatal blow at the supremacy of the Empire."

Happily Their Lordships of to-day are of a different mind and now encourage to the utmost the employment of advanced methods of propulsion and new weapons. Their acceptance of a concept of a "General List" of officers has shown the value they have put on the achievements of technical officers in the past, and by this recognition, the trust they put in the technical officers of the future being able to play an even greater role. It is to fit them to be "all of one company" not only within the Service, but in the technical life of the country as a whole, that the training of officers is now directed.

II—THE SELECTION, EDUCATION, AND TRAINING OF NAVAL CONSTRUCTORS

INTRODUCTION

Probationers for the Royal Corps of Naval Constructors have to be trained for careers in which they may be employed on any of the following duties:—

(a) The design of H.M. ships and auxiliary vessels at the Admiralty in the department of the Director of Naval Construction. D.N.C., who is the Head of the Corps, is the principal technical adviser to the Board of Admiralty and is responsible for the design of all H.M. ships, and in particular for the displacement, dimensions, layout, stability, strength, habitability, speed, and sea-worthiness.

(b) The economic and expeditious construction and repair of H.M. ships in private shipyards. The progress, cost and proper construction are controlled by a headquarters staff in D.N.C. Department and supervised by members of the Corps and their staffs at regional headquarters and at the shipyards.

(c) Research and development on ship forms, propulsion, maneuvering, and sea-worthiness at the Admiralty Experiment Works, Haslar, and on the design of ship structures at the Naval Construction Research Establishment, Rosyth. The Superintendents of these establishments are members of the Corps and their staffs include constructors and scientists.

(d) The construction, repair, and maintenance of ships in the Royal Dockyards. The Constructive Department is the largest department in each dockyard, and the Manager and his senior assistants are members of the Corps. They are responsible for the co-ordination of the general program of dockyard work as well as for the management and control of an industrial staff which may number up to 7,000 men of a dozen or more trades. The Royal Dockyards are administered within the Admiralty by the Director of Dockyards, who is a senior naval officer. His deputy and several senior members of his department are members of the Corps.

(e) A number of posts with other Governments, the Royal Aircraft Establishment, Lloyd's Register of Shipping, the Atomic Energy Commission, on the staffs of Naval Commanders-in-Chief, and at the Royal Naval College, Greenwich.

During his career a constructor may be employed on several, if not most, of these duties, and in his training he must acquire the knowledge and ability to undertake them all efficiently. This calls for a high standard of education in professional and academic subjects, for the development of fresh and resourceful minds receptive to new ideas, and for training in those qualities of character, leadership, discipline, and hard work that lead to good administration and a high standard of professional ability. For the whole of his service a constructor is a civil servant, but when employed afloat or in shore naval appointments he is given a naval rank corresponding to his civil rank in the Corps. During his training he wears uniform and lives in naval colleges under exactly the same conditions as naval officers of his own age, so that, inevitably, he absorbs something of the discipline and self-reliance which these officers exemplify.

BRIEF HISTORY OF THE TRAINING OF NAVAL CONSTRUCTORS

The Admiralty started training its own constructors in 1811 at the first School of Naval Architecture, Portsmouth. This establishment was closed down in 1832, but a second school, known as the Central School of Mathematics and Naval Construction, was opened in 1848, again at Portsmouth, and existed until 1854, when it suffered the same fate as its predecessor. Then for ten years there was no higher education for Admiralty constructors until the Royal School of Naval Architecture was founded at South Kensington in 1864, and since that time the course has continued without interruption. In 1873 it was transferred to the newly opened Royal Naval College, Greenwich, and the main part of the course has remained there ever since, except for a few years in the last war when it was evacuated to Bristol University. The aim was always, and still is, to train a small number of carefully selected students both as ship designers and as ship constructors.

In 1937 a Constructors' Training Office (the C.T.O.) was established in Devonport Dockyard as a center for giving entrants to the course instruction in dockyard administration, practical shipbuilding, and naval architecture. A student may now spend up to two years at the C.T.O. and three years at Greenwich, but these periods are reduced if he has graduated from a university or has had previous shipyard experience.

The essential framework of the course has needed remarkably little adjustment as the years have passed, but the syllabus has been developed continually to meet changing conditions, under the influence of successive D.N.C.s, of committees appointed by the Admiralty and by successive Heads of Departments at the Royal Naval College. From the inception of the course the instruction in academic subjects has been given by a permanent professional staff, but naval architecture has been taught by members of the Corps who have been withdrawn from normal duty for a few years; this has helped to give to the work in professional subjects that sense of reality which the enthusiastic student needs.

RECRUITMENT

Constructor officers are now recruited from apprentices in the Royal Dockyards and private shipyards, from sub-lieutenants at the Royal Naval Engineering College, from university graduates, and from boys at public and grammar schools—in fact the Admiralty has now done everything possible to give young men of suitable ability and education the opportunity to be considered for training for the Corps. A relatively high academic standard is required, particularly in mathematics and science, but where possible this standard is judged by the examinations taken normally during apprenticeship or at school or university. For example, graduates in mechanical science are required to have a first class or good second class honors degree, while candidates from schools must have passed the G.C.E. examinations at advanced level in mathematics and physics. In every case the final selection is made by an interview board of senior Admiralty officers. Some notes on the different methods of entry are given in the Appendix.

The time spent in training the selected candidates depends upon their previous experience and education, and varies from one year at the C.T.O., two at Greenwich, and one at sea for university graduates, to two years at the C.T.O., three at Greenwich, and one at sea for boys who come straight from school. It will be seen that the boy who enters from school gains one year on his fellow who first takes a three-year university course, and this is because all his training from the age of eighteen onwards is directed to preparing him for a career in the Corps.

The present policy is to recruit about twelve students each year, but, due to reasons which will be considered later, only about half that number have been taken in recent years. The course is also open to private students and to constructor officers from other navies; since the war very few private students have entered, but on an average there have been two students per year from Dominion and Allied navies.

PRELIMINARY TRAINING AT THE ROYAL NAVAL ENGINEERING COLLEGE AND C.T.O.

The successful candidates are first sent on a two-week divisional course at the Royal Naval Barracks, Portsmouth, where they quickly become accustomed to wearing their new uniform and to the etiquette and formalities observed by naval officers. At this stage they are usually between 18 and 24 years of age and have ranks of midshipman, sub-lieutenant, or lieutenant, according to age. All except the university entrants then join the Royal Naval Engineering College at Manadon, Plymouth, and stay there for one or two years, depending on their previous experience. During this time they have a course of instruction in dockyard administration and naval architecture at the C.T.O. and, concurrently, attend lectures in academic subjects at the College. From the C.T.O., which is in Devonport Dockyard, they visit ships, building slips, workshops, drawing offices and costings offices to study in detail the work of each trade and the organization and financial control necessary for the building and repair of H.M. ships. They also work on the drawing bench, fairing a set of ship's lines, having practice in the use of planimeters and integrators, and calculating hydrostatic data.

The entrants from universities also spend their first year at Devonport, but live in the Royal Naval Barracks. They have no formal instruction in academic subjects, but devote all their time to the work and administration of the dockyard, lectures in professional subjects, and work on the drawing bench at the C.T.O.

Before joining the Royal Naval College, Greenwich, all the students take short courses in diving and in the operation and construction of submarines.

COURSE AT THE ROYAL NAVAL COLLEGE, GREENWICH

This is a three-year course, but university graduates may go straight into the second year. All the students have the rank of lieutenant and live in the College, although permission to live out ("ashore") may be granted to married officers in the later stages of their training. There are three terms per year and each term is 12 weeks long. Lecture periods are for 70 minutes with a ten-minute "stand-easy" between. The full working week is 9 to 4:30 each day with half days on Wednesday and Saturday, but the students also spend a fair proportion of their evenings and week-ends working in their cabins.

An incentive course of lectures, with laboratory or design room work as appropriate, is given in naval architecture, mathematics, applied mechanics, chemistry, metallurgy, physics, and electrical engi-

neering. Instruction in practical shipbuilding is given at shipyards during vacation courses,

The study periods allocated to the main subjects in the course are shown in Table II.

TABLE II

	First Year	Second Year	Third Year	Total
Naval Architecture	264	360	540	1,164
Mathematics	216	216	216	648
Applied Mechanics	168	216	144	528
Chemistry and Metallurgy.	108	108	—	216
Physics and Electricity	144	—	—	144

NAVAL ARCHITECTURE

The lectures are divided into six subjects: ship design, stability, structural design, resistance, propulsion, and oscillations. Comprehensive notes on these subjects are written by the staff and are continually being revised and reprinted at Greenwich. At the end of each lecture the students are given copies of the notes that have been covered, so that, relieved of the task of taking their own notes, they can concentrate on the lecture and discuss what is being studied. Usually they are also given a sheet of examples which they work out in their own time and then hand in for criticism.

About once a fortnight the senior students attend lectures given by visitors from the Admiralty, the shipbuilding industry, and research establishments. These lecturers are invited to speak on questions about which they have detailed knowledge and experience, and afterwards the students are encouraged to ask questions and to join in a discussion with the lecturer.

It is important that at this stage in their lives the students should have practice in speaking to an audience, and from time to time they give short talks to their own classmates; the experience is heightened when these talks are recorded so that the speakers can hear their own voices played back.

A series of lectures on marine engineering is given by the Head of that department of the College, and naval engineer officers under instruction at the College collaborate with the constructor students for one term and prepare detailed layouts of the machinery installations for the constructors' ship designs.

On an average the students have about four lectures a week in naval architecture and the remainder of their time in the department (about five, six and eleven periods per week respectively in the three years) is spent in the design rooms. The main feature of the work here is the design of a warship, which is started early in the second year and completed by the end of the third year. The students work alone if they design a cruiser or smaller warship, or in pairs if they choose a larger ship. They decide for themselves what type of warship they will design and what its functions, armament, radar, speed, and endurance will be, and they do this with the minimum of advice from the staff as it is important at this stage that they should create an original design. Then, in step with their lectures, they calculate the displacement and dimensions, draw out the form of the ship and small-scale plans of profile and decks, and decide the disposition of the armament, control positions, machinery, accommodation, and so on. Next they calculate the scantlings of the main structure and revise their weight estimates, and finally they draw one-eighth scale plans to decide the detailed layout of each deck and make a more detailed estimate of the total weight of the ship. When completed the design drawings resemble, although they are not in so much detail, the building drawings prepared at the Admiralty before a ship is put to contract.

In the first four terms of the course the students work on the designs that their seniors are preparing, and calculate for them the displacement, hydrostatic curves, stability curves, and longitudinal bending stresses by the standard method. This system, wherein the junior students work as assistants to their seniors, is most successful, both because they learn a great deal from each other and because this lightens the load on the staff of the department.

Apart from the members of the Corps on the staff who check the students' work and advise them on the important features of design, there is also a leading draftsman who spends most of his time on the bench with the students. He checks their detailed layouts of spaces such as galleys, dining halls, mess spaces, and magazines, and runs his experienced eye over their arrangements for access around the ship, boats, accommodation ladders, and so on. They learn from him to appreciate the advice of an older man with many years of practical experience, advice which they will often do well to seek when they are later working at the Admiralty or Dockyards.

When naval officers and members of the Corps visit the department opportunity is taken to let the students show them their designs and hear what criticism may be offered, and at the end of the third year the drawings are carefully inspected by the Admiral President and by D.N.C.

MATHEMATICS

Mathematics, pure and applied, occupies about one-quarter of the study periods and a greater proportion of the students' private study time. The standard in pure mathematics is beyond that of Part I of the mathematical tripos, and in applied mathematics (which includes hydrodynamics and theory of elasticity) it is at least equivalent to Part III of the tripos. This emphasis on mathematics is a traditional feature of the training of naval constructors and experience has shown it to be well placed. It is necessary for the understanding of the more theoretical branches of naval architecture, such as structural design, resistance, propulsion, and ship motion; it is indispensable for the constructors who are appointed to research establishments; it is an inval-

uable tool for ship designers, and it is, at the very least, excellent training in logical thought for any student.

APPLIED MECHANICS

The students take a comprehensive and advanced course in dynamics, mechanisms, strength of materials, fluid mechanics, and vibrations. In the third year they carry out an engineering research in the laboratory, usually on a project of current interest to the Naval Construction Department who, if necessary, help by supplying apparatus or specimens for testing. Some useful investigations have been made, but the most valuable experience gained in this work is in seeking for experimental methods to solve new problems, in assessing the value of the results obtained, and in presenting a clear and concise report.

CHEMISTRY AND METALLURGY

Attention is mainly directed to the chemistry of corrosion and protection, paints and plastics, and to the metallurgy of iron and steel, alloy steels and non-ferrous metals used in warship construction. A good deal of experimental work is done in the laboratory and occasionally some research is carried out in conjunction with structural design investigations in the mechanics laboratory.

PHYSICS AND ELECTRICITY

The lectures and laboratory work cover electrical circuits, electronics, elementary nuclear physics, power supplies, motors and servo-mechanisms, the emphasis being placed on applications to warship design.

EXAMINATIONS

Examinations are set at the end of every term and some of these count as early finals. The finals in mathematics and applied mechanics are set by external examiners from the universities, and those in naval architecture by the Director of Naval Construction and his staff at the Admiralty. To encourage the students to take a broad interest in their profession they are asked in one paper, called Naval Construction (General), to discuss and give their views on some of the more important problems which face warship designers and shipbuilders today. In addition, each student appears before an interview board of senior Admiralty officers at the end of every year.

A complete list of the final examinations and marks is given below:—

Preliminary Ship Design	150
Ship Calculation and Design	250
Structural Design of Ships	200
Resistance and Propulsion	200
Stability and Oscillations	200
Shipbuilding	300
Naval Construction (General)	200
Design Room Work	200
Interview	300
Mathematics I (Pure)	100
Mathematics II (Applied)	100
Mathematics III (Pure)	100
Mathematics IV (Applied)	100
Mathematics V (Class Work)	100
Hydrodynamics	150
Mechanisms and Structures	100
Hydraulics	100
Dynamics of Machinery	100
Strength of Materials	150
Experimental Engineering	200
Chemistry and Metallurgy	300
Physics and Electricity	200

The Admiralty award Professional Certificates to students who reach the required standard in these examinations, a First Class Certificate for over 75 per cent, Second Class for 60-75 per cent, and Third Class for 40-60 per cent. On an average about one-quarter of the students obtain first class certificates. The initial selection of students for the course is made with such care that it is almost unknown for any of them, except an occasional foreign student, to fail to obtain at least a second class certificate, which is the minimum necessary for entry to the Corps.

These examinations are in a sense competitive since the students' order of seniority on first appointment to the Corps is based on their performance in the Greenwich finals. They certainly take them very seriously—in fact their industry and enthusiasm for their work have become a tradition at Greenwich and add considerably to the pleasure of being appointed to the professorial staff.

VACATION COURSES

In addition to occasional visits to works during the term the students spend nine weeks of the Easter and summer vacations each year taking courses at dockyards, private shipyards, the Admiralty Experiment Works at Haslar, the Naval Construction Research Establishment at Rosyth, the Naval Gunnery School and the Damage Control School. The great value of the vacation courses, as with the preliminary training at Devonport Dockyard, is that the students become acquainted with the equipment, techniques, and craft skill of the industry, with the organization that manages it, and with the outlook of the men they may one day be called to control. They are also, of course, a welcome break from the concentrated academic study at Greenwich. The visits are carefully planned and, while some lectures are given by the staffs of the establishments, greater emphasis is placed on studying the work in ships, shops or laboratories and in not staying in offices except for the minimum time needed for making notes or studying drawings. During these courses the students prepare notes and sketches of the work they have seen in progress, and these are handed in for checking and criticism before they leave.

SEA TIME

On successfully completing the Greenwich course all constructor officers are sent to sea for twelve months, and in this time they usually serve in three or four of H.M. ships of different types. While at sea

they are required to study the behavior of the ships they are in, the internal organization at various states of readiness for action, and the conditions under which officers and men work. Although not charged with any specific duties they usually take an active part in the life on board and spend some time working in each department of the ship.

During their year at sea they learn to appreciate what the designer can do to produce ships that will be efficient in action, will behave well in bad weather, and will be comfortable and popular with the ship's company. They also benefit from the communal life on board and the visits to foreign places, so that they return with increased confidence in their own training and experience, and eager to begin their careers in the Corps.

GENERAL REMARKS

A naval constructor is thoroughly trained to do a job which is vital to the Navy, and during this training he enjoys a standard of living and an opportunity for social and other activities which are as good as in any university in the country. When his training is complete he is appointed to a succession of responsible posts, all of which are full of interest for the individual, so that he generally has a varied and professionally satisfying career. Further, the salaries paid to the Corps are the highest in the professional Civil Service. It might then be thought that there would be great competition for what would appear to be an attractive opening for young men of the right quality, but, in fact, there have been so few suitable candidates since the war that the Admiralty has been able to enter only about half the number wanted.

For the last twenty years the main sources of recruitment to the Corps have been the dockyard technical colleges and the universities, and there are different reasons for the failure of each to continue to produce the number of men required. With the dockyard entry it is largely due to changes in the national education system which enable many more boys from grammar schools to take scholarships to universities, and they generally prefer this to taking up apprenticeships. As a result of this the educational standard of dockyard apprentices has fallen and fewer have been considered suitable for entry to the Corps.

One reason for the failure to recruit more graduates from universities is that some are daunted by the prospect of three more years tough academic training. Another is that men with the qualifications required by the Admiralty may be offered better salaries by private engineering firms. When choosing a career, however, the varied experience and interest of the work, and the security and conditions of service, must also be considered, and on these counts, entry to the Corps is an attractive opening for any young man who is interested in ships and shipbuilding. Certainly the graduates who have come in recently, an average of about two per year, have thought so, but the question is, why not more? A little experience in this field soon makes the reason quite clear—it is that in the greatest shipbuilding country in the world almost nothing is known in most of the universities about how ships are designed and built, so that very few undergraduates ever give any consideration to a career in shipbuilding. The anomaly becomes obvious if we compare with the aircraft industry, with its many university courses, and its large share of the output of graduates each year. Yet shipbuilding is of greater value to the country, both in turnover and in numbers employed, and there are surely at least as great commercial gains to be won by improved performance and economy of ships as of aircraft. Unfortunately the lack of interest in recruiting more graduates suggests that shipowners and shipbuilders do not appreciate that this would improve their ships, and that such improvement is needed and would increase their trade and profit. The Admiralty has not failed to realize the value of highly trained naval constructors, but the general indifference to a professional career in shipbuilding has contributed to the difficulty in attracting recruits from universities.

As usual, to define the problem is to indicate ways in which it may be solved, and this has led the Admiralty to make two important changes in its recruitment policy, both started last year. The first was to enter a new stream of student apprentices to the Royal Dockyards with more attractive terms of employment and the guarantee of at least a draftsman's job at the end of the apprenticeship. It is hoped that this will appeal to boys of a higher educational standard and that it will be possible to select more constructor officers from the fourth year of student apprentices than has been possible from recent entries of craft apprentices. The second change in recruitment started last year was the direct entry to the Corps of boys from public and grammar schools. These boys must be between 18 and 19½, and their educational standard must be similar to that required for entry to a university—in fact it is hoped to attract boys who would otherwise go to a university to study mechanical science or engineering, the attractions of the Admiralty appointment being in salary, the high standard of living in the naval colleges, and a training which compares favorably with that of any honors degree course.

There are grounds for hoping that, with additional recruitment from these sources, the Admiralty will soon have the number of constructor students required to bring the Corps, in due course, to the strength necessary for its vital duties. Neither international politics nor the advent of new weapons gives any reason to suppose that the Navy will not be indispensable to this country for as long as can be foreseen, and the very existence of the Navy depends on a strong and efficient Royal Corps of Naval Constructors.

APPENDIX

ENTRY TO THE ROYAL CORPS OF NAVAL CONSTRUCTORS

Probationers for the Corps are drawn from five sources:—

Source A: From Apprentices in H.M. Dockyards

The Royal Dockyards have a system for training and educating apprentices which is recognized as one of the best in the engineering world. The apprentices have part-time education at the Dockyard Technical Colleges, but only the most able and diligent are allowed to complete the full four-year course, the standard of which approximates to the ordinary B.Sc. degree course in engineering. Those apprentices who reach a sufficiently high standard in the final examinations are invited to appear before an Admiralty selection board and, if considered suitable, are offered appointments as constructor sub-lieutenants.

Source B: From Sub-Lieutenants at the R.N.E. College, Manadon

Sub-lieutenants at the Royal Naval Engineering College may apply to become constructor sub-lieutenants. If considered suitable they are transferred at the end of their fourth term.

Source C: From University Graduates in Mechanical Science or Engineering

Candidates usually apply during their final year at the university and then appear before a selection board. Their acceptance depends on this interview and on their obtaining a first class or a good second class honors degree at the end of the university course.

Source D: From Apprentices in Private Shipyards and Graduates in Naval Architecture

Candidates have to give satisfactory evidence of adequate academic and technical education, and of having been engaged in practical shipbuilding for at least eighteen months. In the case of university graduates less practical experience may be accepted. Approval has recently been given for young draftsmen and technical grades in H.M. Dockyards also to apply for entry in this way. All applicants have to appear before an interview board and, if considered suitable, they have to pass the Greenwich Entrance Examination.

Source E: From Boys at Public and Grammar Schools

Candidates must be between 18 and 19½ and they are required to have passed the G.C.E. examination at Advanced Level in pure mathematics, applied mathematics, and physics. Passes at Ordinary Level in English and one other language are also required. Applicants appear before an interview board and those selected are offered appointments as constructor midshipmen.

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VALUE ENGINEERING IN THE BUREAU OF SHIPS

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INTRODUCTION

"More ships for less dollars" is the motto of the Value Engineering office of the Bureau of Ships. This in a few words describes the Navy's new engineering approach to reducing the cost of its ships and the equipment that goes on its ships. By the use of this new management technique, the Bureau has been able to achieve substantial savings in the procurement of some of the equipment under its cognizance at a time when costs are constantly rising.

BACKGROUND

In the early 50s, the Bureau of Ships was aware of being caught in the squeeze of constantly rising costs, and the trend toward reduction of government expenditures. A submarine which cost $4 million in 1933 was costing $23 million in 1953, a destroyer costing $3.6 million in 1933 had risen to $31.7 million in 1953. Coming even more up to date, shipbuilding costs across the board went up approximately 510 percent from 1939 to 1955. At the same time, the consumers' price index, or the cost of living index, put out by the Department of Labor went up 180-185 percent. The question naturally arises as to why has the cost of our ships increased so much in proportion to other cost increases; and even more important, how can we combat these cost increases?

The answer to a part of this question is that our ships have increased in complexity, habitability has been improved, electronic requirements have been tremendously increased, labor and materials have gone up and in general we have ships of much more fighting capability. The advent of nuclear power promises further increase in costs of ships. However, when all of these factors are removed, we still have a remainder which does not represent good value. Much of this discrepancy or excess cost for value received has been generated by the "habits and attitudes" of our military designers, specification writers, and equipment engineers as well as their counterparts in industry. This will be elaborated on in a later paragraph.

To help in obtaining an answer to the second part of the question, how to combat these rising costs, the Bureau sent a group to industry to see if anything new was being done in the way of attacking this problem. It was found that many things were being done. This new approach to reducing costs was called by many names in industry. But the one program which seemed more nearly in line with the Bureau's aims was the Value Analysis Program at the General Electric Company. This program had then been in effect for several years, and had shown tremendous results. This group came back to the Bureau, and instigated the birth of the Value Engineering office as Code 109, a staff office to the Chief of the Bureau. This office was formally established in April 1954.

At the present time the office is composed of a Captain, USN as Director of Value Engineering, a Commander, USN as Assistant Director, ten engineers and three secretaries. The ten engineers are divided as follows: two as assistants for Electrical Engineering; two as assistants for Marine Engineering; two as assistants for Mechanical Engineering;

two as assistants for Naval Architecture and two engineers as assistants for Electronics.

The duties as set forth in the Charter are:

(a) Establishes specific objectives of the program.

(b) Establishes procedures and methods necessary for the coordination of the program.

(c) Initiates and conducts Value Engineering studies of specific projects where the need is indicated.

(d) Provides advice and assistance to the Assistant Chiefs of Bureau of the technical divisions as necessary to achieve program objectives.

(e) Establishes and maintains liaison with other government organizations and private industrial firms engaged in similar programs.

(f) Indoctrinates Bureau personnel in Value Engineering, and disseminates Value Engineering techniques within the Bureau.

REASONS, OR NEED FOR VALUE ENGINEERING

As previously stated, some of the so-called "Habits and Attitudes" of designers, specification writers, equipment engineers and architects in industry and the government are in a large part responsible for our increased equipment and shipbuilding costs.

A habit, by dictionary definition, is "a tendency toward an action which by repetition has become spontaneous."

An attitude is "that state of mind or mental readiness which predetermines a response to something." We are all creatures of habit in our day-to-day existence. Without habit, we couldn't tie our tie, or drive a car, or do the many things that are required of us.

Then in familiar situations to which we re-act from habit, we gain a sense of security. Psychologists tell us that most of us in some degree or another have a dislike of being in an unfamiliar situation. It makes us feel uncomfortable, and insecure. Therefore, when we are in situations to which we can react from habit, we get a feeling of security.

Unfortunately this can be carried too far to the point where we refuse to face, or admit that a situation is new and try to find a new solution for it. Instead, we try to react from habit and fit an old solution to a new problem. This in a large part defeats any effort to be progressive, and to make improvements.

These habits and attitudes are instilled in most of our military designers for many reasons. First because they are people and subject to all human failings, and secondly, because they are dealing in many cases with human lives. You have all heard the phrases, "nothing is too good for our boys," "the best is always the cheapest," "men's lives are at stake," and many other platitudes which are partially true, but in many instances are used only as an excuse to justify the high cost of an item, or to resist any tendency to change a piece of equipment. This safety complex is carried to the extreme in many of our military engineers. And the peculiar part is that such a safety complex is so strongly evident in a business or profession which is one of the riskiest in the world, that of warfare.

However, one must view the military engineer's job in the proper perspective to appreciate why he has such a safety complex and reacts so strongly from habit.

An *original designer* has the problem of designing a piece of equipment which—first, will work,

second, work reliably,

third, be capable of being produced practicably and usually within a relatively short time.

Many times, or most often, he is working against deadlines, so time becomes of the essence.

Then the *specification writer* has the job of—first, changing the design and requirements into written words and to make sure that *minimum* requirements are met. To insure this, he usually makes the requirements somewhat stricter than necessary to make sure that no loophole exists.

Then the *production man* has the job of changing these specifications into physical requirements to suit the tooling equipment and deadlines he is given.

In the military, all of these problems exist. But further is the implied necessity of never leaving room for error. The equipment must work, when needed; after all a ship might be lost, if the particular piece of equipment fails. It must be foolproof, because sailors are many times untrained and unskilled in its operations. It must be shockproof, to withstand gunfire, it must be waterproof and it must be capable of being easily repaired. When you add all of these requirements on to a piece of equipment, you can begin to see why the military engineer's job is so difficult. The primary emphasis in every case is on *reliability*. To make sure it works! Cost in this picture has gone from being of primary importance, as in civilian goods, to practically no importance or hardly worthy of consideration. But even if the cost is considered, how can a military engineer tell if he is being charged too much? After all, most of the Navy's requirements are peculiar to the Navy, produced by specialized producers and there is hardly any basis for comparison with any civilian product. Then further, the engineer is usually facing an imminent deadline and is mostly concerned as previously stated, with reliability.

Under these circumstances, costs have become something of minor importance to many technical people.

Reliability has become the chief criteria or standard of performance. Unlike private industry, which has the profit motive and its yearly profit and loss statement to keep it ever aware of reducing costs, the Navy has no such criteria. Thus, reliability has become its criteria. After all, the engineer's job is judged on how well his equipment works not how little it costs.

Therefore, it was necessary that some office be created whose primary responsibility was cost, and cost reductions. However, as a staff code, the Value

Engineering office has no real authority or responsibility for changing technical requirements. As in any other staff office, it conducts studies, offers ideas and counsel, and makes recommendations to the technical people whose responsibility it is to accept or reject these recommendations. The Value Engineering office acts as a service organization for Bureau technical codes, pointing out areas of high cost, sometimes suggesting methods of reducing the cost, or alternate methods of achieving the same function. But in any case, it only recommends and the technical code still has the technical responsibility. It can accept or reject these recommendations. And when it accepts them, the technical code deserves the credit for the savings generated. Value Engineering Offices have been set up in each of the eleven Naval Shipyards where a good portion of the Navy's money is spent. These offices are staffed with three to four value engineers and generate many of the value engineering projects. If necessary, they are sent into the Bureau of Ships for approval or disapproval by the cognizant Bureau branch. Value engineering projects are required to be completed staff studies, with present and proposed methods or items. The detailed costs and savings to be generated by acceptance of the proposal are on the project card. All pertinent facts should be contained therein. The idea is to present the project in such a form that the cognizant engineer without additional work on his part can accept or reject it. For example, in the case of two technically accepted methods of performing a function, the cost would be the deciding factor.

TECHNIQUES OR METHODS OF THE VALUE ENGINEER

Now that the *why* part of high cost of naval equipment is somewhat explained, the second part of the question remains to be answered. How can these costs be reduced. Through a thoroughly planned approach to high cost, keeping in mind the habits and attitudes of people which make them reluctant to change, the problem is attacked scientifically. The value engineer has a list of some twenty techniques that he uses as necessary to obtain his primary purpose; maximum function at minimum cost.

To begin with, he uses an overall Job Plan. This job plan is broken into five phases or steps. They are as listed below.

(a) The Information Phase
(b) The Speculative Phase
(c) The Planning Phase
(d) The Execution Phase
(e) The Reporting Phase

These phases are broad overall areas which give the value engineer guidelines in planning, executing and carrying out a value engineering project, and bringing it quickly to a logical conclusion, with efficient use of time and effort. With these phases to guide him and with his attention centered on the Reporting Phase, the value engineer will avoid the trap of holding out for a perfect solution. If he tries for perfection, he will never attain any solution. He must suggest the best possible alternate, technically acceptable and as inexpensive as possible, in the time available.

Within each phase of the Job Plan, the value engineer uses various specific techniques. (See Addendum 4 for listing.) Four major basic techniques are:

a. Get the Facts—Know the Cost.

With this technique, the value engineer concentrates on facts, facts as to actual requirements, questioning requirements that do not seem necessary. He gets complete plans and specifications. He questions specifications that seem unnecessarily restrictive. He puts cost on each component of the particular equipment. Procurement costs, maintenance cost and cost on every piece and on each manufacturing operation. If done properly, the high cost, low value parts stand out for him to concentrate on. This is one of the hardest parts—getting facts, and getting costs.

As an example, a small commercial transformer cover used by the thousands, was found to cost 42c. When costs were detailed, it was found 17c went to making the metal part, and 25c into painting the cover, or it cost almost twice as much to protect the cover as the cover cost—17c vs 25c. Then the cover was changed from painted to electroplated for preservation at a cost of 3c—saving 22c per cover or a 53% reduction in cost—just by getting costs and facts.

Remember, deal in specifics—in facts—not generalities or opinions.

b. Evaluate or Determine the Function.

This is one of the most important of all techniques. It is more or less the heart of value engineering. With this particular technique, you use another technique, called "Blast." With this technique, aim at taking 70-90% of the cost out of the item. This causes you to ignore the item or component itself and determine the function it is to perform. If the item is made up of several parts, determine the function of each part. Try to determine function with two words, a verb and a noun. For example—using the transformer cover again. The purpose of the cover was just that—to cover or protect the transformer. This was its primary function—it cost 17c. The function of the paint was to protect the cover, a secondary function. So when the function was determined and the costs put on each function, it could be seen that a secondary function was costing considerably more than the primary function. Relate the cost of each area to the function it performs. Use three of the five basic questions you will continually use:

1. What is it?
2. What does it do?
3. What does it cost?

You are then ready to move to the next technique called—

c. Evaluate by Comparison.

With this technique you compare the function and cost you have determined, with the function and price of a comparable commercial item, or something from some other completely different field. You do this every day in your daily life. If you need shoes, or a suit, you compare suits with other suits for quality, price, etc. Once you have decided on what you want, then you usually buy the one that has the most to offer for the lowest price.

The value engineer compares the function desired, with a similar function from another field. This will then give him an idea as to how much the particular function he is trying to achieve should cost. For example—take a low level illumination light as used by the thousands on naval ships to provide enough light under blackout conditions, to enable personnel to get around the ship. The light as presently used is a 25 watt light covered with a red globe, about 6 inches in diameter by 8 inches long and it's waterproof and shockproof. It costs $12.60. Considering its requirements, that seems to be a fairly reasonable price. But, compare its function—low level illumination with a commercial night light available in any hardware store for 39c. Our light does not look so good. The same function, but at 3% of the cost. Of course, it's probably not shockproof and waterproof, but are these functions really necessary? And even if they are necessary, are they as secondary functions, worth 97% of the cost? No, of course not. They could be added to the principle of the commercial light, and still should not run the cost up more than $1.50 or $2.00.

So you can see what can be achieved by "Evaluate by Comparison."

d. Creative Thinking.

This technique has been used in problem solving probably more by Alex Osborne and people in the advertising agencies, than most anywhere else. Yet it has proven successful time and time again, to bring new and fresh thinking to old problems.

One of the most used approaches is to have a "creative session" or "brainstorming session." In this approach, you bring four or five people together, preferably in a small private room. One person is appointed to be the recorder, and a basic problem is presented. The object is to get the maximum number of ideas recorded in a given time. Turn off the judicial mind, and allow no negative thinking. One individual throws out an idea which stimulates an idea in another's mind. No idea is too silly. It may stimulate an entirely new train of thought in someone else's mind. It takes a little time to get the group warmed up and over the habit of evaluating an idea mentally before broaching it. But once started, ideas flow freely. After ten or fifteen minutes, they begin to come more slowly. Then finish the session and begin to evaluate the ideas. You will be surprised at the many new approaches to solving a problem you can come up with.

As an example of creative thinking, consider the use of cable banding as a method of securing electric cables on board ship. The method used for years, was to individually measure each run and custom make a strap to suit. By association of ideas, and seeing how large cartons were strapped with bands of steel tape, an electrician in a West Coast yard came up with the idea of strapping cables in place. This idea has already saved the Navy hundreds of thousands of dollars.

It has been said, "We have passed through the age of random creativeness and are entering an age of deliberate creativeness." "Creative thinking is a process of achieving by the application of self-generated ideas."

METHODS OF SPREADING VALUE ENGINEERING

Seminars.

When it was decided to multiply the efforts of the value engineering office by spreading into the naval shipyards where most of the ships' work is done, the problem of how to effectively train the people as value engineers arose. Again, following the General Electric Company's lead, the three-week seminar was used. By bringing individuals into a new environment, taking them away from their routine work, surroundings, etc., it was possible through intense 8-hour a day effort to change these people's outlook in a matter of a few weeks, and send them home enthusiastic and carrying the work of this new program.

To date, the Bureau has conducted two large scale three-week seminars and several smaller ones. Seminars are broken up into a series of lectures on value engineering methods and techniques by Bureau Value Engineering people, lectures on Bureau organization and responsibility by pertinent Bureau people, a large number of vendor exhibits and talks on new products and processes, and actual work on selected value engineering projects. These projects are presented to management on the last day in a sort of graduation ceremony showing savings achieved.

Through the use of these seminars, the Bureau has trained all of its shipyard value engineers, now numbering approximately 45, some private contractor personnel and personnel from many other government agencies.

In addition to these large scale full-time seminars, half-day and fifteen-hour seminars, as well as 3 to 5 hour seminars have been outlined for use in acquainting shipyard workers and management people with the program.

The Office of Value Engineering, as a way of acquainting organization with its program, has made many brief introductory presentations. These presentations have been made to many shipbuilders and equipment manufacturers, as well as many Department of Defense officials and other government agencies. The presentation generally takes the form of an introduction by the Director, explaining why

value engineering is necessary. Then several civilian engineers give talks on "Habits and Attitudes," "Techniques" and value engineering incentive clauses. The program is usually concluded with a question and answer period. The pace of these presentations is kept up by changing speakers every fifteen to 20 minutes. To date, all of these presentations have been enthusiastically received.

RESULTS TO DATE

Initial Study.

One of the first projects attempted by the Value Engineering office, was the study of an LCVP (Landing Craft Vehicle Personnel). It is a 36-foot boat of early World War II design. Its purpose is to haul about 20 people from a ship to shore safely or a cargo of small vehicles. Since 1942 the Navy has procured 24,000 of them. The 1955 budget had funds to procure 1,000 of them. The study, conducted by the entire office in approximately three months, resulted in 25 recommendations, nineteen of which were accepted by the technical people concerned. Several more have since been implemented. Each of these recommendations was detailed with specific costs, facts and savings. All were based on *actual* operational requirements and the concept of maximum required function at minimum cost. Several of the recommendations are as listed below:

1. Use impregnated fir plywood in place of marine mahogany plywood as specified. Savings—$224 per boat, $224,000 total for 1000 boats.

2. Redesign fuel tanks. Use four standard 45-gallon drums coated to prevent corrosion instead of specially designed copper nickel tanks. Savings—$460 per boat, $460,000 total for 1000 boats.

3. In place of circuit breakers, use fuse and clip. Savings—$38 per boat, $38,000 total for 1000 boats. All in all, the contracts were placed at $3,000 less per boat than previously, and in a time of rising costs. The 1000-boat procurement was reduced from approximately $13 million to $10 million. A savings of $3 million, with no reduction in function or reliability. These recommendations have been applied to other boats, and enlarged upon so that the $3 million was only the beginning.

Naval Shipyards.

Since this early beginning, the emphasis in the Value Engineering office has shifted from specific project work to training and administration, even though selected projects are still worked on. Ten engineers could not possibly begin to even scratch the surface on savings in an organization that currently spends over 2 billion dollars a year on shipbuilding. Therefore, it was decided to multiply their efforts. So value engineers in all naval shipyards were trained and units set up. They send in project cards to the central value engineering office. When possible, local approval is gained. If not, the cards are sent in directly to the cognizant technical section, with copies to the value engineering office. Where projects are of sufficient size dollar-wise, or require coordination with several technical groups or more information, or for any justified reason, the Value Engineering office takes a paternal interest in the project card to insure its receiving the proper consideration and attention. To date, approximately 1100 projects have come from the shipyards, the majority of which have been accepted. Savings have run approximately eight to one over the cost of operation.

Private Shipyards.

The next field to be explored after the naval shipyards was the private shipyards. Here, 3 times as much money is spent on ship construction as in naval shipyards. The problem here was to provide an incentive for the shipbuilder to want to reduce the cost of shipbuilding. Under our ordinary contracts, the shipbuilder was, in effect, penalized for suggesting cost reductions. His contract is usually based on cost plus a certain specified profit. When he suggested a less expensive way of doing something, he was rewarded with a change order which revised his costs, and *profit* downward and resulted in a costly bookkeeping operation for him. So he was actually being penalized for suggesting less expensive ways of doing things. A value engineering clause was worked up for shipbuilding contracts. Under this, the shipbuilder is required to furnish at his expense, two value engineering specialists for full-time work on contract plans and specifications. He sends in reports similar to those from the naval shipyards, for acceptance or rejection by the Bureau. The Bureau trains these specialists in the practice of value engineering. The shipbuilder receives 45% of the savings engendered by his value engineering project, and the Bureau keeps 55%, thus providing an incentive to reduce the cost of shipbuilding.

To date, only a few selected contracts have been let in the shipbuilding field. One nuclear submarine shipbuilder, after 8 months of operation under this clause, has realized $113,000 as his share on savings brought about by value engineering projects. The Bureau has realized $363,000. Applying these items to additional nuclear submarines, further savings of $615,000 should be realized by the Bureau.

Electronic Equipment.

In the equipment area, it was decided to apply value engineering to electronics first because of the large quantity of electronic equipment bought directly by the Bureau. Three considerations were used in selecting areas for cost reduction studies:

1. Broad specifications for certain specific applications are excessive as contrasted to similar commercial applications.

2. Periodic "second looks" for economy should be required for all designs starting with the pre-production study.

3. An incentive for the production contractor is needed to make him criticize constructively the Navy's requirements.

To meet these needs, a specification was developed. It concerns value engineering of naval electronic equipment and is MIL-V-19858. It requires the manufacturer to perform a value engineering study and provide a feed-back of information to the man who writes the specifications. The Bureau will pay for the cost of these preliminary studies and then in the production contract, the incentive clause, allowing the manufacturer to keep a percentage of the savings, is used. Action is now underway to use the value engineering specification and incentive clauses in approximately eight electronic equipment contracts totalling about $20 million dollars.

There are many pitfalls and much to be learned on both sides in the use of these incentive contracts. But it is a part of the Bureau's efforts to make the contractor and the Bureau operate as an efficient team to provide the maximum defense at minimum cost. Much of that learned in these preliminary contractual areas will be applied in other fields.

FUTURE

The direction of the office of value engineering in the future will be to consolidate those areas in which it is now operating and to extend the value engineering application to private contractors in other equipment areas; to develop methods to use more extensively the operating forces as a means of originating value engineering projects and to enter the field of maintenance and repair in private facilities.

CONCLUSION

With several years of operation behind it, the Value Engineering office has only begun to scratch the surface. A comparatively few men working full time have been able to achieve quite a measurable influence, even on an organization as large and sprawling as the Bureau of Ships and its associated field activities. Aside from the measurable effect, the intangible effects of changing people's attitudes towards cost and making them aware of high cost areas so they themselves will look for less expensive means of achieving the same function is tremendous. Further than this is the year-after-year application of value engineering savings, which are tabulated only in their first year of application.

However large the gains may be to date, they are only a beginning, with the ultimate aim of having a highly efficient Navy sufficient to perform its assigned mission at a minimum cost to the taxpayer.

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ADDENDUM I

EXAMPLES OF SAVINGS EFFECTED BY VALUE ENGINEERING

1. Use of commercially available foamed plastic insulation for refrigerant and chilled water piping systems in place of previously used cork.

Savings on two nuclear submarines—$77,533

2. Shooting studs for cable and electrical appliance supports through a hole cored in insulation without removing the ferrule, cleaning or painting welded area and patching insulation.

Savings on two aircraft carriers, CVA 60 and 62—$169,642.82

3. Elimination of flame proof bedding covers where fire retardant mattresses are used.

Savings on two aircraft carrier ships—$81,200

4. Substitution of elbow union in place of specially designed flange on cooling coil condensate drains on aircraft carriers.

Savings on one carrier—$8,197

5. Changed method of renewing boiler uptake expansion joint and substituted welding for bolting, eliminating removal of interference to bolting and allowing expansion joint to be installed from inside boiler.

Savings—$54,400—Maintenance renewals on destroyers at one naval shipyard during one year.

6. Substituted welded bolt hold down in replacement of engine girder hold down bolts instead of special K-monel angular nuts on minesweeper.

Savings on 22 vessels—$62,348

7. Substituted commercially procured aluminum extruded gratings for store rooms and cold storage spaces in place of shipyard manufactured.

Savings for one year at one shipyard—$40,000

8. Changed method of acoustically treating overhead hangar bay on CVA 62.

Savings—$37,360

9. Use of portable rig to machine packing sleeves at stern tube section of main propulsion shafting on destroyer instead of removing packing sleeve and sending to machine shop.

Savings for one year at one shipyard—$135,000

10. Use of sealing compounds on leaky head gaskets on low pressure evaporator instead of replacing gaskets.

Savings for one year at one shipyard—$55,700

11. Procured stowage rack, for air duct hose, as separate item instead of with each section of hose as previously done.

Savings—$70,336

12. Redesign of mechanism for erecting and lowering of a submarine ship antenna to use commercial parts instead of shipyard manufactured.

Savings—$115,865

13. Use of commercially procured draw curtain hardware in place of shipyard manufactured.

Savings on CVA Class—$6,670

ADDENDUM II

REQUIREMENTS FOR VALUE ENGINEERS

A Value Engineer should be either a graduate engineer or have the equivalent in experience. The majority have experience in more than one particular field. Some come from design, production, inspection or purchasing. Most of them have more than ten years' experience in engineering. Some other characteristics considered essential are:

1. *Initiative.* A value engineer must initiate and develop much of his own work. Very rarely does the job come to him.

2. *Perseverance.* The value engineer must see his project through to acceptance, or in a few cases, rejection by the line people. He must not be discouraged along the way by "Roadblocks" and obstacles he may encounter.

3. *Imagination.* The value engineer must have the ability to see possibilities in obscure ideas, and the ability to think "creatively" for new solutions to problems.

4. *Fluency.* The value engineer must be able to express himself orally and in writing. He must be able to convince people in small conferences and be able to talk to large audiences of technical people.

5. *Literacy.* The value engineer must be able to write reports easily understood, but with all the necessary facts to enable line people to make decisions based on his reports, with no further effort on their part.

6. *Diplomacy.* The value engineer must be able to convince people at all organizational levels—from the lowest working level to the highest management level.

7. *Dissatisfaction.* He must be dissatisfied to maintain the status quo because he knows there must be a better way. Most all progress has been made by people dissatisfied with the way things are.

8. *Value Consciousness.* He must have a good idea of value. He must be able to sense items which cost more than their function is worth.

9. *Technical Competence.* He must be technically competent in his field, and respected, so his judgment is accepted.

General Qualifications

The value engineer as a staff man, must understand the line and staff relationship. He must be able to appreciate management's problems and policies. He must be part teacher to train others, part lecturer to spread the value engineering idea, part psychologist so as to understand what motivates people. He must have an extreme awareness of cost and its relative importance in matters. Where the line engineer responsibility is primarily for reliability and maintainability, the value engineer must keep these in mind, but at minimum cost. The value engineer must understand and make use of new ideas, new processes and products.

Obviously there are very few people who possess all of these qualifications. The best approach is to have a balanced group of people with these various attributes operating as a team. This is what the Bureau of Ships has attempted to do.

ADDENDUM III

TESTS FOR VALUE

EVERY MATERIAL, EVERY PART, EVERY OPERATION MUST PASS THESE TESTS

1. Can we do without it?
2. Does it do more than is required?
3. Do you think it costs more than it's worth?
4. Is there something better to do the job?
5. Can it be made by a less costly method?
6. Can a standard item be used?
7. Considering the quantities used, could a less costly tooling method be used?
8. Does it cost more than the total of reasonable labor, overhead, material and profit?
9. Can someone else provide it at less cost without affecting dependability?
10. If it was your money, would you refuse to buy the item because it cost too much?

If the answer to any of the above questions is YES, then you are not getting good value. SEE YOUR NEAREST VALUE ENGINEER.

ADDENDUM IV

OUTLINE OF VALUE ENGINEERING TECHNIQUES

1. *Work on Specifics—not Generalities*

Value Engineering has its very basis in specifics. Define the problem—single out certain areas; clean them up systematically.

2. *Use the Value Engineering Job Plan*

All jobs can be broken down into simple steps and any job is better carried out by a planned program one step at a time.

3. *Get "All" the Facts*

This is a realistic hard-boiled job—costs, inventory, usage, specs, development history, etc. We find that in half the cases when all the facts are supposed to be in, they're not! We find that unless we get more facts than anyone else has, we miss untold opportunities. You can't work without all the facts. When you don't have facts you are using personal opinion. Get all of them. Many times a problem solves itself when you get all the facts. You can't work on a basis of opinion.

4. *Put a Dollar Sign On Each Main Idea*

Know how much your ideas are worth. Never try to evaluate them until you have some idea of the possible dividends in return for your invested time.

5. *Know The Cost in Detail*

Know the cost of every part and operation. We can't determine value without good cost figures. It's surprising how little is known about cost.

6. *Get all Your Information From The Best Sources*

Get all your information from the best sources—not just the normal source—not the one that we are in the habit of using—but the *best* sources.

7. *Determine Each Function*

Evaluate each function, that is divide the product into functional areas, relate the cost of each area to the function it performs. Think clearly with regard to function and ask yourself these questions:

1. What is the item?
2. What does it do?
3. What does it cost?

8. *Evaluate the Design or Functional Area by Comparison*

Enrich the present problem by drawing from a different field. Whether or not a design represents good value can be determined by using this technique. Compare with a commercial item performing the same function. Compare the object with a toy—toy makers have to be low cost. In many cases lower cost methods or principles will be discovered. Continue with the basic questions of Value Engineering:

1. What else will do the job?
2. What will that cost?

9. *Bring New Information Into Each Functional Area*

Bring new information into each functional area by using specialists. Not only specialists within your organizations, but draw on the huge technical resources of other industries. If it is a fastening problem, consult an application engineer or a company which specializes in fastenings. If it is a question of material or process, get in touch with a company which is out in front in producing or applying the material or using the process. Try to keep ahead of everyone in new technical developments which promise equal or better performance at less cost. This is one of your strongest weapons in obtaining better value.

10. *Use Your Own Judgment*

If you don't think it's right, it probably isn't—do something about it! After properly getting the facts, you know more about it than anybody else. Do something about it.

11. *Use the Creative Approach*

Turn off the judicial part of the mind; allow no negative thoughts, really concentrate on creating ideas as to how a function can be performed.

12. *Blast!*

Try to take out one-half the cost from most functional areas and nine-tenths the cost from some components. By so doing you will be forced into new areas—areas that have not been previously explored. Consequently, you many find it easier to remove 50% or 90% of the cost than to remove the customary 5% to 10%.

13. *Use Standards*

Search out applicable standards—use commercial standard items when possible. There are thousands of plans in file where special bolts are detailed—a little redesign might allow the use of a bolt out of a stock bin—at 25% of the cost of a special bolt.

14. *Consult Specialty Vendors*

Use specialty products, materials and processes. Use them in the determination of prices. Put vendors engineers on your team.

15. *Use The Techniques of Good Human Relations*

Frequently, this is half the problem. Don't argue. Give people time to change—never appease. Deal properly but not weakly. Bring your discussions to the point quickly and courteously. Treat all people with dignity. Give credit where due. If you must fight—fight willingly but on your own level.

16. *Identify and Overcome Roadblocks*

Don't be stopped by shadows. If a roadblock occurs, define it as clearly and as sharply as possible and then set about to overcome it.

17. *Spend The Navy's Money As You Would Your Own*

Everything we do is committing our country's money. Commit the Navy's money, exactly the way you would your own. You would be surprised how easy that makes decisions. We don't advocate violating policies but policies are man-made to govern the mass of decisions that must be made daily. They are supposed to be man-changed whenever the Navy's interest benefits. Ask yourself these questions—what would I do if it were my money or if it were my money would I be willing to pay that much for it?

18. *Act, But Be Brief!*

Get your thoughts on paper—your only product. Your recommendations will be reviewed by busy men. They must be factual and highly refined staff work—a presentation which permits decision by the technically responsible authority.

Recognizing the success and importance of Value Engineering in the Navy, the editors of Marine Engineering/Log have exhorted commercial builders and operators to cut costs by a similar attack. Three areas of effort were suggested: new materials, new ideas, and human engineering. The increasing use of plastics and more consideration of the possibilities of aluminum were advocated as examples of possible economic gain in the use of new materials. Perserverance in putting across new ideas was urged as a necessity of progress and of economic improvement. The planning and cultivation of proper relations between management and workers to develop teamwork was advanced as an important area in cutting costs. "Just because it has always been done a certain way is no reason why it should continue as standard practice," the editors noted.

—from "Marine Engineering/Log"
December 1957

"THE MARINE ENGINEER & NAVAL ARCHITECT"

NUCLEAR PROPULSION FOR MERCHANT SHIPS

ACKNOWLEDGEMENT

This is an abstract of a paper presented to the Institution of Engineers and Shipbuilders in Scotland on 25 June 1957, as published in the September and October 1957 editions of "The Marine Engineer and Naval Architect." The authors are Dr. S. L. Smith and Dr. J. E. Richards of the British Shipbuilding Research Association.

THE first use of nuclear power for ship propulsion will entail replacing the conventional boiler by a nuclear reactor with associated steam-raising equipment, and possibly later the reactor will replace the combusion chamber of a closed-cycle gas turbine. In present designs of reactor, although the utilization of the nuclear fuel is not very high, the direct fuel cost with natural uranium as a fuel is much lower than oil fuel costs. It is true that the capital costs of the plant may outweigh the lower fuel costs but this is indicative of the early stage of development.

The cost of nuclear power may be divided into two parts. The first represents the initial capital investment in the reactor. The second is the fuel cost, which may also be regarded as in two parts: (*a*) the investment in the first charge of nuclear fuel and (*b*) the cost of replacing the spent fuel which is expressed in pence per shaft horsepower-hour and is known as the direct fuel cost. The present economics therefore depend upon balancing these two factors but the future prospects, with technical advance, are high utilization and hence even lower direct fuel costs coupled with reduced capital costs.

This country has embarked on a big program of nuclear power stations and there is every indication that for large base-load stations, nuclear power will be competitive with coal. The next stage of development may well be the smaller electrical power stations such as are required in more sparsely populated countries, and merchant ship propulsion. From a national point of view, there are reasons why we should go ahead with the building of nuclear-powered merchant ships as soon as they show promise of being commercially attractive. We are a trading nation and cheap marine transportation is essential for our livelihood. Only recently has the full realization of the dependence of the country's economy on imported fuel oil from the Middle East been brought home to us and our position will be strengthened when nuclear power provides the means of propulsion to some of our merchant ships.

It does not follow that we should rush ahead with the building of nuclear-powered merchant ships without due regard to safety. Damage can be caused by the widespread dispersion of the radio-active fission fragments which are by-products of the nuclear reactor and it is essential that the designs of reactors evolved for marine propulsion should be such that they present no hazards unduly greater than those accepted at present in marine and industrial practice.

SUPPLY OF NUCLEAR FUEL

It is important to realize that in this country we are at a very early stage in the development of useful power from nuclear energy. The foundations of this new industry were laid by the building of facilities for military purposes and, because of their military value, nuclear fuels are controlled by national agencies and as yet there is neither an international agency nor a free market.

The basic material in which we are interested for providing nuclear power is natural uranium, which contains only 0.7 per cent of the fissile isotope uranium-235, the remainder being uranium-238. The low concentration of nuclear fuel in this material creates problems in reactor design which can be eased if

the uranium is enriched in 235 content, but the enriching process in a diffusion plant is expensive and consumes a considerable amount of electrical power. However, the wide application of nuclear power to marine propulsion is unlikely to be achieved without the use of enriched uranium.

In the United States the first step in power reactor development was the pressurized-water reactor, using enriched fuel, installed in the submarine *Nautilus*. In this country it was the gas-cooled graphite-moderated natural uranium reactor at Calder Hall built primarily for the production of military plutonium. In the United States enriched fuel is produced in large diffusion plants built for military purposes with cheaper electricity supplies than are available in this country, where supplies of enriched fuel are limited at the present time. The United States is prepared, under certain conditions, to sell enriched fuel to overseas countries at a price which corresponds roughly to the cost of natural uranium plus about £6 for each grm. (£2,700 per lb.) of added uranium-235. She is also prepared to sell natural uranium and heavy water.

It is evident that in present circumstances, progress in the development of nuclear power can only take place by co-operation between industry and Government. The United Kingdom Atomic Energy Authority has the responsibility in this country for the provision and control of nuclear fuel, for research, and for the initial stages of reactor development.

FUEL CYCLES AND COSTS

All the reactors with which we shall be concerned in this discussion of nuclear propulsion are called "thermal reactors." The nuclear fuel is the 235 isotope of uranium and the fuel rods are of natural uranium (which contains only 0.7 per cent U-235, the remainder being U-238) or uranium enriched in the 235 isotope. Fission of the nuclear fuel produces heat, fission products and a number of fast neutrons. The fission products are radio-active and the fuel is canned to prevent their escape into the coolant stream which removes the heat generated. The fast neutrons are slowed down in the moderator to thermal energies and cause further fission, thus maintaining the chain reaction. Some of the neutrons are captured by the uranium-238 to form plutonium, a secondary fuel, a small percentage of which is burned as the reaction continues. Eventually it is necessary to withdraw the fuel elements due to loss of reactivity or because of metallurgical limitations, and the remainder of the plutonium is removed from the spent fuel elements by chemical processing.

NATURAL URANIUM

In the operation of the natural uranium power reactors which are being built in this country it is hoped that about 3,000 MW.-days of heat will be extracted from each ton of uranium before the fuel elements are removed from the reactor. About 3 of the 7 kg. of uranium-235 in each ton of natural uranium will then have been burned and chemical processing of the used fuel elements will yield about 2 kg. of plutonium per ton. The reactor is refueled with a fresh charge of natural uranium. Although this cycle of operations leads to only about three-sevenths of the fuel being consumed, the direct fuel cost on the basis of 3,000 MW. of heat per ton of uranium is only about 0.2 pence per s.h.p.-hr., about half that of a modern oil-fired installation. It should be noted that the low direct fuel cost which can be achieved with this cycle of operations depends on the amount of heat which can be extracted from each ton of fuel before recharging and if this is less than 3,000 MW.-days per ton the direct fuel cost will increase accordingly. The direct fuel cost also depends on the credit given for the plutonium produced.

ENRICHED FUEL

Because of the high cost of enriched fuel a more complex cycle of operations is necessary when this is used. The used fuel elements would be chemically processed to remove the plutonium produced and the depleted uranium would be re-enriched in a diffusion plant. While it is true that this process leads to a high degree of utilization of the uranium-235, as most of it is recovered in the diffusion plant, there is no indication that the direct fuel cost would be any lower than for a natural uranium-fueled reactor. This is because of the high cost of fabrication, chemical processing and enriching. When enriched fuel is used it is possible to build in an appreciable amount of excess reactivity and to consider fuel elements of uranium in other than the metallic state. Types of fuel element can be used which will withstand a large burn-up of uranium-235 and in this way chemical processing and fabrication charges per unit heat output are reduced. In a recent American design of pressurized-water reactor using enriched uranium oxide fuel pellets in stainless steel cans it is estimated that it will be possible to extract 8,000 MW.-days of heat per ton of uranium before the fuel elements are withdrawn. The estimated fuel cost, including fuel investment charge, on the basis of United States prices, is given as the equivalent of about 0.2 pence per s.h.p.-hr. Thus while the use of enriched fuel does not appear at the present time to lead to lower direct fuel costs than with natural uranium, it does permit a wide range of reactors to be considered and more robust fuel elements than those at present used in natural uranium reactors.

As it is unlikely that wide application of nuclear power to marine propulsion can be achieved without the use of enriched uranium, the possible way in which such systems will be developed in this country is a matter of some importance. Appreciable quantities of plutonium will be produced as a by-product from the natural uranium reactors which are to be built in this country for the power station program and in the 1955 White Paper it was anticipated that this fuel might be used for the enrichment

of natural uranium for advanced types of reactor. This plutonium will not begin to be available in quantity until about 1965 and both the method and economics of its use are not yet clear.

Theoretical studies indicate that it may be possible to get a fairly high degree of utilization of natural uranium by making use of the plutonium produced, but this is only likely to apply to natural or very slightly enriched systems. This is because less neutrons are produced from plutonium fission than from uranium-235 fission per neutron absorbed.

TYPES OF REACTOR

Before discussing various types of reactors it is appropriate to mention four of the characteristics of a reactor which are of importance from an economic point of view.

The basic component of a reactor is the fuel element with its coolant channel and surrounding moderator. For a given design, with fixed enrichment of the fuel, there is a minimum size called the critical size of reactor core to achieve a chain reaction. The size of the core of a power reactor must be somewhat larger than this critical size to obtain sufficient reactivity to take care of fuel depletion and poisoning. The tonnage of uranium in the core represents a capital investment in fuel, the monetary value of which will vary with the enrichment of the fuel. The average heat rating, usually measured in MW of heat per ton of fuel, when multiplied by the tonnage of uranium in the core gives the total rate of heat output and therefore settles the maximum horsepower of the plant. The interest on the fuel investment per s.h.p.-hr. will vary with the heat rating and the utilization of the reactor. Another factor of importance is the total heat produced or burn-up before the fuel elements are withdrawn from the reactor either for metallurgical reasons or because of loss of reactivity, and this is usually measured in megawatt-days of heat per ton of fuel. From the marine point of view the overall diameter of a reactor is also important as on this will depend to a large extent the weight of biological shielding which has to be installed, which detracts from the cargo carrying capacity of the vessel.

There are so many variables in reactor design and so little experience that is is not possible to generalize on their characteristics but these are discussed with reference to particular systems. The particular systems discussed are those already developed and those which may be developed in the near future.

GAS-COOLED GRAPHITE-MODERATED REACTOR

This type, using natural uranium as a fuel, is being developed in this country for land power generation. The Calder Hall reactor is shown diagrammatically in Figure 1. The moderator of the reactor consists of a large number of graphite blocks built in the

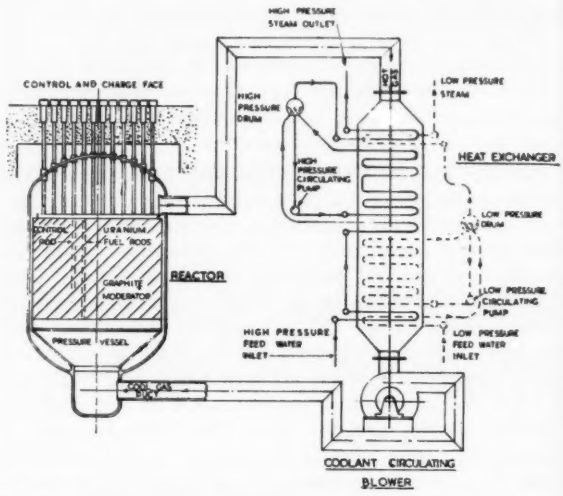

Figure 1—Arrangement of Calder Hall gas-cooled graphite-moderated reactor and steam-raising plant.

form of a solid cylinder having a diameter of 36 ft. and a height of 27 ft. and weighing over 1,000 tons. It contains a large number of vertical channels in which are stacked rods of uranium metal canned in a magnesium alloy. The heat generated in the 130 tons of uranium rods is removed by carbon dioxide gas at 100 lb. per sq. in. which flows up through the channels over the surface of the rods and passes at a temperature of 350°C to the heat exchangers. The gas leaves the lower end of the heat exchangers to pass through the blowers, which re-circulate it to the lower end of the core. A dual-pressure steam system is used and each heat exchanger is made up of banks of stud welded tubes consisting of H.P. and L.P. economizer, boiler, and super-heater sections. Steam is led to two 23-MW. turbo-alternators per reactor, the electrical output of which will be 42 MW. at full load from a reactor heat output of 180 MW. The power output of the reactor is regulated by control rods which can be raised or lowered in special channels in the core.

The core is contained in a steel pressure vessel about 40 ft. in diam. and 60 ft. in height fabricated from steel plates 2-in. in thickness. The reactor vessel is surrounded by a thermal shield of 6-in. mild steel plates to absorb the thermal neutrons escaping from the core, and outside this is a concrete biological shield. The space between the thermal and biological shield is used for induced draft air cooling. Charging and discharging of the fuel elements are carried out through the charge tubes.

The use of natural uranium as a fuel places severe limitations on the design of this type of reactor and makes it essentially a large reactor having a considerable investment of nuclear fuel. Current designs use cylindrical rods of natural uranium a little over 1 in. in diam., contained in finned cans of magnesium alloy, and a heat rating of about 2 MW. per

ton is achieved. This leads to a fuel investment charge of about 0.05 pence per s.h.p.-hr. and with the expected burn-up of 3,000 MW. of heat per ton, the direct fuel cost is likely to be of the order of 0.2 pence per s.h.p.-hr. The steam temperature is limited to about 700°F by the maximum permissible temperature of the magnesium alloy cans. A probable development is the use of beryllium for canning and this would enable the steam temperature to be raised. The Calder Hall reactors have a fuel charge of 130 tons but it is known that reactors of this type can be built with somewhat smaller cores. Even so, the weight of the reactor and shield would be several thousands tons and the pressure vessel diameter of the order of 30 ft.; the only possible application would be to very large vessels. For power outputs of less than about 60,000 s.h.p. the capital cost of the reactor per s.h.p. may well be so large that it is not attractive commercially. If a supply of slightly enriched fuel were available at a reasonable price this type of reactor might be attractive for smaller outputs and a wider range of vessels because the tonnage of fuel and size of the reactor could be reduced considerably.

GAS-COOLED HEAVY WATER REACTOR

A reactor of this type has not yet been built but several countries appear to be interested in this system. A design for a gas-cooled heavy water reactor has recently been proposed in the U.S.S.R. The general arrangement and the form of the fuel channel are illustrated in Figures 2 and 3. Within the reactor pressure vessel is a light-alloy tank pierced

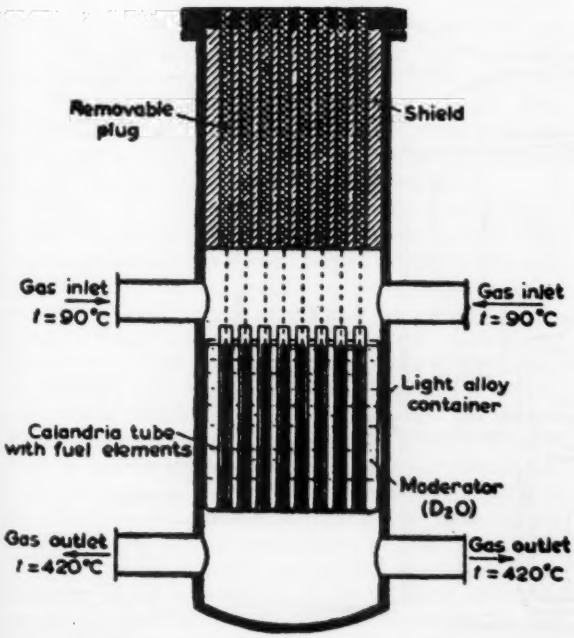

Figure 2—Gas-cooled heavy water reactor.

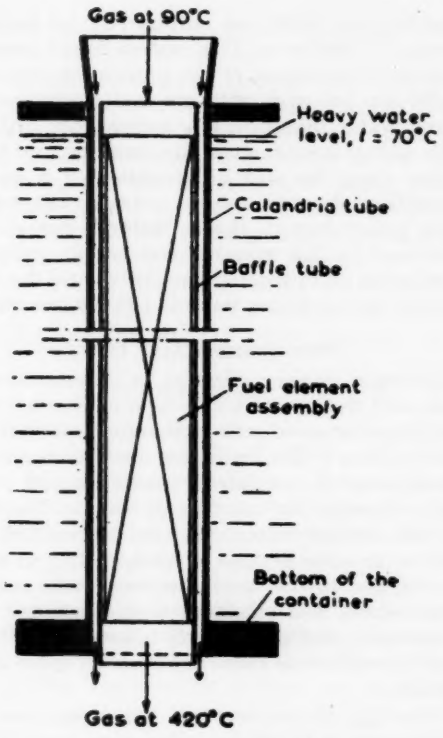

Figure 3—Calandria tube.

through with calandria tubes. The tank is filled with heavy water and the fuel elements are suspended in the calandria tubes from removable plugs in the upper shield. The fuel elements consist of rods or plates of natural uranium clad in a light metal which withstands a maximum temperature of 550°C and are enclosed in a light alloy baffle tube. The narrow annular gap between the baffle tube and calandria tube forms a passage for gas cooling of the tubes. The temperature of the calandria tube is kept low and the coolant and the heavy water are kept at the same pressure so that there are virtually no pressure stresses in this tube. Carbon dioxide is used as a coolant at a pressure between 590 and 880 lb. per sq. in. and the gas enters the reactor at 90°C and leaves at 420°C. A dual-pressure steam cycle is adopted.

The use of heavy water instead of graphite introduces engineering complications but heavy water is an excellent moderator and a fuel investment as small as 15 tons of natural uranium may be practicable with a pressure vessel diameter of perhaps 15 ft. The moderator/uranium volume ratio is of the order of 15 to 25 compared with over 45 for graphite; consequently the core size is smaller for the same fuel investment and this is advantageous from a marine point of view. The smaller size permits higher gas pressures, giving higher heat ratings and smaller heat exchangers. The weights of reactor and

shielding for 20,000 shp output may not be much in excess of 2,000 tons. This system might possibly be economically attractive for powers of the order of 20,000 shp but even with gas cooling the cost of the heavy water investment is appreciable, although if high ratings are achieved this cost may not be much higher than the cost of graphite for a gas-cooled graphite-moderated natural uranium reactor of the same power output. Heavy water is not at present produced in this country but recent estimates of production costs are not prohibitive and the recently quoted United States price is £20,000 per ton.

PRESSURIZED-WATER REACTOR

Hydrogen is very effective in slowing down neutrons and the use of water as a moderator leads to small reactor cores with moderator/uranium volume ratios of 2 or 3. The hydrogen does, however, absorb an appreciable number of neutrons and enriched fuel is essential for this type of reactor. The moderator and coolant water must be pressurized to prevent, or in some designs to limit, boiling in the core. The oxygen in the water becomes radio-active and emits γ-rays, and shielding of the primary circuits is necessary, but this activity is very short-lived and is not troublesome from the point of view of maintenance.

Although development of the pressurized water reactor was initiated for submarine propulsion this reactor is now being applied in the United States to other classes of naval vessels, to electrical generation on land and to America's first nuclear-powered merchant ship.

Some feature of this type of reactor can be illustrated (Figure 4) by reference to details of an American design of pressurized-water reactor for a power station. The reactor produces 480 MW. of heat from a core 74 in. in diam. by 100 in. in height, the primary water pressure is 2,000 psi and the reactor vessel 109 in. in internal diam. by 8 in. in thickness. The coolant inlet and outlet temperatures are 487° and 529° F respectively and dry saturated steam at 521 psi is generated. Uranium metal reacts strongly with water and is not favored for this type of reactor. In this design the basic element of the fuel element assemblies is a pellet of uranium oxide 0.30 in. in diam. and 0.30 in. in height. Three hundred and forty pellets are assembled in a 0.015-in. wall thickness stainless steel tube to make a fuel rod with an active length of 102 in. The enrichment of the fuel is 2.6 per cent U_{235} and about 15 MW. of heat are produced per ton of fuel in the core. It is anticipated that a burn-up of 8,000 MW.-days of heat per ton will be achieved before re-processing is necessary.

The core consists essentially of a cylindrical assembly of the fuel element rods housed inside a pressure vessel. The water is circulated at a fairly high velocity to secure the required rate of heat removal and passes from the reactor to the steam generator, from which it is pumped back to the reactor vessel. The pressurizer is fitted with electric heaters to obtain the required working pressure and also serves as an expansion chamber.

In the design of a pressurized water reactor problems arise from the high system pressure, the cor-

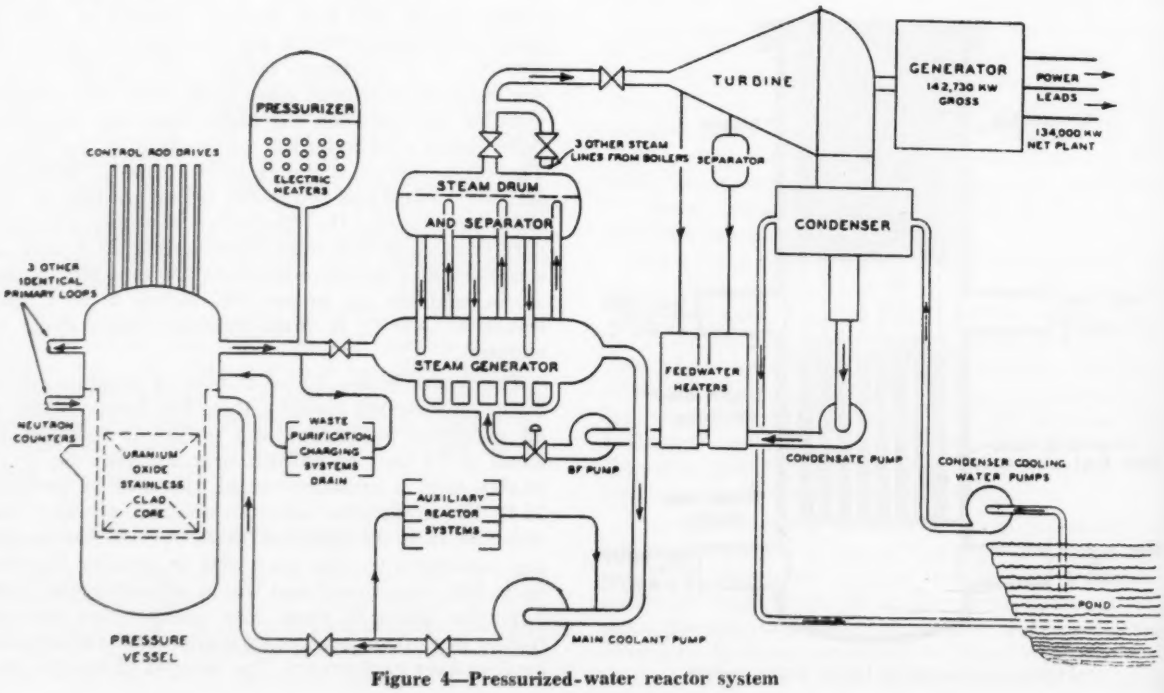

Figure 4—Pressurized-water reactor system

rosive action of the water under irradiation, the activity of the primary circuit, and the poor steam conditions. In present designs containment is provided for the vapor which would be flashed off in the event of a failure of the primary circuit and for this a massive pressure vessel is necessary.

ORGANIC LIQUID-MODERATED AND COOLED REACTOR

Organic liquids are used in industry as heat transfer media and certain classes of these liquids such as the polyphenyls have sufficiently good stability under temperature and irradiation to be considered as reactor coolants. The hydrogen density in these hydrocarbons is nearly as high as that of water and from the point of view of core size, enrichment of fuel, and direct fuel cost, an organic liquid reactor may be expected to be very similar to a pressurized-water reactor. A reactor experiment to test an organic liquid as a moderator and reactor coolant is being built in the United States and is expected to start operating in the near future.

A schematic flow diagram of an organic liquid reactor for use in a power station having a gross electrical output of 12,500 kw is shown in Figure 5, from which it will be seen that a gas pressurized system is incorporated in the design and that facilities are proposed for organic liquid purification and make-up. The proposed steam conditions are 415 psig, 520° F.

Organic liquids have certain potential advantages over water as a coolant and these include low vapor pressure, low chemical activity and low induced activity. The low vapor pressure permits a much lower pressure in the primary circuit and this may be in the range 40—150 psi; it also eases the problem of containment. The absence of significant induced activity should make shielding of the primary circuit unnecessary and might well obviate the need for complete leak tightness of the primary circuit. The negligible corrosion of conventional materials of construction such as mild steel and aluminum makes the use of expensive materials unnecessary.

Against these advantages have to be set certain disadvantages of organic liquids for reactor use. The proposed liquids have low thermal conductivity and specific heat, which result in poor heat transfer properties, and it may be difficult to achieve a sufficiently high heat rating for the fuel investment charges not to be excessive. They break down under irradiation, and at temperatures above about 400° C the rate of breakdown increases rapidly. Although the polymerization products may be sufficiently soluble in the liquid for coking on the surface of the fuel elements to be no problem, means of moving the products of polymerization would have to be provided. The most promising liquids from the point of view of stability are not liquid at room temperature and trace heating of the primary circuit is necessary. Another point is that there might be fire and toxicity hazards. Whether or not these advantages of organic liquids offset the disadvantages remains to be seen and at present time all that can be said is that if an organic liquid reactor is feasible it will probably be cheaper than a pressurized water reactor and that the design would not be so far removed from that of conventional plant.

It has already been mentioned that for the same power output the size of an organic liquid reactor may be expected to be about the same as a pressurized water reactor. A reactor producing 20,000 shp might have a pressure vessel diameter of 6 to 7 ft. and a shielding weight not much in excess of 500 tons. The capital cost of such a system may well be sufficiently low for smaller power outputs to be economic.

OTHER TYPES

Several other types of reactor have been proposed for ship propulsion, but all of these are enriched systems. In the United States the Atomic Energy Commission and the Maritime Administration have announced a joint long-range program for developing reactor systems for commercially competitive propulsive power for merchant ships, in addition to the work now in progress on the first nuclear-powered merchant ship. The two agencies have contracts with private companies for six design feasibility studies. The reactor systems are as follows:

Study	*Company*
Organic-moderated and cooled reactor	North American Aviation Inc.
Closed-cycle gas turbine with gas cooled reactor	Ford Instrument Co.
Closed-cycle gas turbine with hydride moderated, helium-cooled reactor	General Dynamics Corp.
Boiling water reactor	A.M.F. Atomics Inc.
Close-cycle gas turbine graphite moderated, helium-cooled reactor	General Motors Corp.
Advanced type pressurized water reactor	Babcock & Wilcox Co.

It would appear that the fairly low cost of enriched fuel in the United States will make it possible to consider systems requiring appreciable enrichment.

NUCLEAR POWER IN SHIP PROPULSION

It seems likely that in this country the commercial application of nuclear power to the propulsion of ships will not be possible for some years to come unless natural uranium-fueled reactors are found to be attractive for this purpose, or unless enriched fuel is available at a reasonable price. Until enriched fuel is available the possible field of application is severely limited. As far as can be seen, the main advantage to be gained by the use of nuclear power is the promise of low direct fuel costs. The question arises whether lower fuel costs would lead to higher

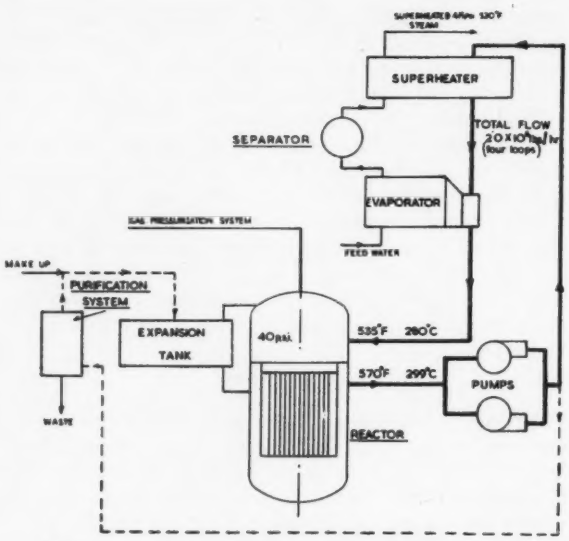

Figure 5—Flow diagram of an organic liquid reactor

speeds and increased earning capacity and whether the saving in the annual fuel bill, if an increase in speed is not justified, is likely to make worth while the additional capital investment for the reactor.

Very few ships have powers higher than 20,000 shp, which may be the minimum for which large natural uranium reactors are attractive, but the trend towards larger oil tankers for the transport of crude oil is increasing the number of vessels in this category. There are many reasons favoring oil tankers for the first application of nuclear power and during the past year increasing interest has therefore been taken in the possible use of nuclear power for the propulsion of the large oil tankers which might be used in the future to transport crude oil to this country from the Middle East by the Cape route. In the past the depth of the Suez Canal has limited the size of tankers for this trade, but the consumption of oil in Europe is growing at such a rate that the closure of the Suez Canal has merely brought forward the time when the Cape route must be considered.

FOR 45,000 TONNERS AND ABOVE

The power and speed of typical large tankers is given in Table I and it is evident from the 20,000 shp just mentioned that the possible application of natural uranium reactors is likely to be limited to tankers of about 45,000 tons deadweight and above. During the last year there has been a rapid increase in the number of large tankers on order and in service throughout the world. In July 1956 there were 8 vessels over 40,000 tons deadweight in service or launched and 79 building or contracted. The corresponding figures for January 1957 are 21 and 190 respectively.

A feasibility study has been carried out by B.S.R.A., with the co-operation of tanker owners, of the application of nuclear power to large tankers and it is of interest to refer to the results for single-screw tankers of 47,000 dead-weight tons. This is a class of ship which is likely to be built in fairly large numbers during the coming years and there is a possibility that a gas-cooled heavy-water moderated natural uranium reactor might be attractive for the propulsion of these vessels. When enriched fuel becomes available graphite or hydrogen-moderated reactors can also be considered.

TABLE I—*Representative Large Tankers*

Owner	Dead-weight tons	shp	Speed, knots	Remarks
British Tanker Co.	32,000	12,500	15	Single screw. A large number of 28,000-32,-000-ton tankers have been built since 1950.
Niarchos	47,750	18,000	17	Delivered 1956. The largest tanker built in United Kingdom. Single screw.
Tidewater Assoc. Oil Co.	65,789	22,000	17	Building in France. Single screw.
National Bulk Carriers	85,515	19,500	14½	Built in Japan. Delivered 1956. Single screw.
Niarchos	106,500	43,000	18	Twin screw. Ordered in United States.
(Current trend)	47,000	16,000	15¾	Single screw.

NUCLEAR PROPULSION FOR 47,000 TONS TANKER

The method adopted in this study is to calculate, on the basis of certain assumptions, the cost of transport per ton of oil delivered from the Middle East to the United Kingdom in a conventional tanker and to make similar calculations for equivalent nuclear-powered vessels in which the deadweight is reduced due to the additional machinery and associated structural weight. For these nuclear vessels the cost of transporting oil has been calculated for (*a*) a range of nuclear fuel costs, including fuel investment charge, and (*b*) a range of figures by which the machinery and associated structural weight might be regarded as additional to that of the conventional vessel. The saving in cost of transporting oil in a nuclear tanker as compared with the cost for a conventional vessel is capitalized in each instance. From this saving is calculated the additional capital expenditure which could be incurred on the reactor and associated steam-raising equipment of the nuclear vessel for it to be commercially competitive with the conventional ship.

The conventional vessel taken for the basis of this study is representative of current trends in this country and is a 15¾-knot, 16,000 shp, 47,000 ton

tanker. It was decided to determine the permissible reactor cost of a 47,000 ton nuclear-powered vessel with 16,000 shp and also for a vessel of the same deadweight with 22,000 shp. The reason for including the higher-powered vessel was to see whether an increase in speed would be justified with nuclear propulsion. Consideration of the adjustment of the proportions and fineness of the 47,000-tonner and an estimation of the approximate service speed to suit the increase in power from 16,000 to 22,000 shp was a necessary preliminary to the economic appraisal and the results are given in Table II.

In increasing the power the basic design has been lengthened and made finer in accordance with the Alexander formula, which ensures that ships are not "overdriven." Allowance has been made for the increase in hull and machinery weight with increase in hull length and power respectively and this is reflected in the slightly increased displacement with increasing power. The different designs refer to conventional machinery and for nuclear-powered vessels the deadweight has to be reduced to allow for the increase in machinery weight.

TABLE II—*Estimated Speed and Appropriate Dimensions of 47,000-ton Tanker with Increased Power*

shp available	16,000*	22,000
Appropriate dimensions—		
Length, ft.	710	743
Breadth, ft.	102.5	103.5
Draft, ft.	38	38
Block coefficient	0.785	0.754
Displacement, tons	62,300	62,950
Propeller diam., ft.	22.5	24.0
Service rpm	106	106
rpm for onset of cavitation	115	107
Service speed, knots	15¾	17
Quasi-propulsive co-efficient	0.646	0.649

*Current trend

For the conventional vessel, the bunker prices ruling at November, 1956, are taken, and for the nuclear-powered vessels fuel costs, including investment charge, of 0.2, 0.3 and 0.4 pence per shp hr. "all purposes" were assumed. The increase in the machinery and associated structural weight of the nuclear-powered vessels above that of the conventional vessel was taken at 500, 1,500, 2,500 and 3,500 tons in each case.

One of the routes considered for the comparison was from the Middle East to the United Kingdom via the Cape in both directions, as being an example of a long voyage. The load-carrying capacity of the conventional ship on this route varies throughout the year as the ship is loaded to the maximum permitted by the freeboard regulations. There is a Winter Zone in the South Atlantic for about 6 months of the year and roughly the other 6 months in the North Atlantic. In consequence the nuclear-powered ships have to be loaded to their winter marks throughout almost the whole year whereas the conventional vessel can load bunkers additional to the winter deadweight, provided these are consumed at such a rate that the vessel is at her winter marks when entering the Winter Zone. The yearly average deadweight was taken for the conventional ship and it was found that the cargo carried in the nuclear and conventional ships was the same when the additional machinery weight of the nuclear-powered vessel was 1,700 tons. For an additional machinery weight greater than this figure the nuclear ship carried less cargo and for a smaller weight it carried more cargo than the conventional vessel.

BASIS OF FIXED CHARGES

In the economic analysis November 1956 prices for bunkers were taken and other running costs were based on 1957 levels. It was assumed that the latter costs would be the same for the nuclear-powered vessel as the conventional vessel and that the time out of service and the time per voyage for loading and discharging cargo were also the same for all ships. There were no reasons for suggesting that different values should be taken, but it was realized that if there were any differences between the vessels in respect to these items, they would materially affect the results of the study. For the purposes of calculating the capital charges, the cost of the conventional ship was taken at January 1957 figures (£3m.). The capital charges assumed for this investigation are made up of depreciation over 20 years (5 per cent), 6 per cent interest on the reducing capital (3.15 per cent average) and an insurance rate of 1.25 per cent, making 9.4 per cent in all. The same rates were taken for the nuclear-powered vessels, but it should be noted that the charges for such vessels, particularly the insurance charge, may in fact be higher.

From the difference between the transport cost per ton delivered to the United Kingdom in the nuclear ships and the conventional vessel was calculated the capital which could be expended on the nuclear-powered vessels above that on the conventional vessel to give the same transport cost per ton of oil delivered. From these capital sums a first approximation to the permissible cost of the reactor and steam raising equipment was obtained by adding the cost of the conventional boilers. For the higher-powered nuclear vessel the additional cost of the finer hull and the additional cost of the machinery was subtracted. The results are given in Table III for a nuclear fuel cost of 0.2 pence per shp-hr. An increase or decrease in the nuclear fuel cost of 0.1 pence per shp. hr. results in a decrease or increase in the permissible reactor cost of £530,000 for the 16,000 shp 47,000 tonner and £720,000 for the 22,000 shp 47,000 tonner. It follows that the nuclear fuel cost would have to be very small, much less than 0.2 pence per shp hr., before increased speed of operation would lead to an increase in permissible reactor cost, on this basis of analysis.

An increase in the price of bunkers of 0.1 pence per shp hr. (about 33s. per ton) results in an increase in the permissible reactor cost of about £540,-

TABLE III—*Premissible Reactor Cost. 47,000-ton d.w. Nuclear-Powered Tankers*

Nuclear fuel cost 0.2 pence per shp hr.
Voyage: Mina/U.K./Mina via the Cape

Vessel	Cost	Additional machinery weight, tons 500	1,500	2,500	3,500
16,000 shp 15¾ knots	Permissible cost, £m.	1.45	1.29	1.13	0.98
	Permissible cost/s.h.p. £	91	81	71	61
22,000 shp 17 knots	Permissible cost, £m.	1.28	1.11	0.94	0.78
	Permissible cost/s.h.p. £	58	51	43	35

000—£500,000, reducing with increasing machinery weight, for the 16,000 shp vessel and £580,000—£540,000 for the 22,000 shp vessel. If the depreciation is taken over 16 years instead of 20 years with the same rate of interest, the permissible reactor cost is decreased by about £8 to £11 per shp and if the depreciation is taken over 24 years the permissible reactor cost is increased by roughly the same amount. It may be concluded that provided the direct fuel cost of nuclear power is low, the additional investment which can be justified on the basis of this analysis is appreciable, and it remains to be seen how far this goes towards meeting the cost of a reactor. The calculations made are for a particular route and are mainly useful in giving an indication of the relative importance of direct fuel cost, capital cost of plant, and additional machinery weight.

There has been much speculation as to whether the advent of nuclear energy might change the economics of ship-owning. All the authors' investigations show that this is not so but that the first most likely competitive application will be a large ship, for which higher powers are appropriate. For larger vessels than those considered, nuclear power is undoubtedly more attractive but the field of application is smaller as there are reasons apart from cost of transporting oil which limit the requirement of large tankers. For very large tankers the possibility that a graphite-moderated natural uranium reactor might be economically attractive cannot be ruled out. At the same time they cannot envisage any fanciful changes in ships' forms as a result of nuclear power. Except perhaps to the eye of the naval architect and marine engineer, nuclear ships will look much the same as conventional ones.

SOME PRACTICAL CONSIDERATIONS

The marine application of nuclear power will introduce many engineering problems and in this section attention is drawn to some important practical considerations in the nuclear propulsion of merchant ships. In natural uranium-fueled reactors the uranium is in metallic form and although there is as yet little experience of the performance of such fuel elements when subjected to the extended burn-up necessary to achieve a low fuel cost, there is every indication that the incidence of failures would be such that provision would have to be made for the removal and replacement of faulty fuel elements at sea. Least complication would be introduced if this operation were carried out with the reactors shut down, and the ship could proceed at part speed using steam from an auxiliary boiler. If the incidence of failure were high much time would be lost on voyage if this procedure were adopted and provision would have to be made to change fuel elements when under load, as in the Central Electricity Authority stations, but this facility would be expensive and probably difficult to arrange.

When the more expensive enriched uranium is used there is much more scope in fuel element design and it may now be possible to develop fuel elements which are sufficiently robust that provision for changing fuel elements at sea would not be necessary, and that failures would be so rare that they could be considered as a major breakdown, like the failure of a tailshaft. If a coolant is used which does not react with the uranium or the uranium is dispersed in a material which does not react with the coolant, the build-up of activity in the primary circuit following a failure of a fuel element may be so slow that the voyage can be completed before it is necessary to change the faulty element on this account. Special care will have to be taken with the support of the fuel elements as vibration might be induced not only by the flow of coolant over the surface but by vibration of the hull.

Control

Only a very small amount of excess reactivity can be built into natural uranium reactors and if high heat ratings are achieved, there may be some difficulty in starting up immediately after shut-down due to transient xenon poisoning. The heat capacity of natural uranium reactors is large and also it is doubtful whether thermal cycling of the uranium metal fuel elements could be permitted. Consequently it is likely that a dump condenser to take the full-power steam output would be installed and this could be used for maneuvering, and to overcome difficulties from transient xenon poisoning. With enriched systems the fuel elements may be made sufficiently robust and the engineering design may be such that maneuvering by varying the power of the reactor may be possible. A reactor system is well suited for automatic control and it could be that a smaller number of watch-keepers would be required than for oil-fired boilers. While the authors do not wish to discuss the personnel required for a nuclear vessel they do wish to dispel the popular belief that a crew of highly qualified scientists will be required.

Shielding

The conclusion was drawn from the study of the application of nuclear power to 47,000 ton tankers that each ton of shielding reduced the permissible cost of the reactor by about £160. Consequently

there is much to be gained from methods of reducing the weight of shielding below that of the usual 8 ft. of concrete. Any reduction in shielding weight may also extend the field of application of natural uranium reactors to smaller vessels. For some applications such as oil tankers, some use may be made of the cargo for part shielding, but use of this expedient might be limited by operational considerations and the requirement that the hull structure should not be permitted to become active and make repairs and maintenance difficult.

Machinery arrangement

It seems probable that in a nuclear-powered tanker the reactor would be installed just forward of the steam turbine and it might be necessary to encroach on the cargo space. With the large natural uranium reactors there may be some difficulties regarding trim and hull strength and the reactor might have to be sited somewhat further forward. There would almost certainly be some structural problem in providing a rigid seating for the reactor and yet allowing for the flexing of the hull in a seaway. Access would have to be provided to the reactor through the upper deck and compensation would be required for the loss of longitudinal strength. Additional turbo-generators would be required to provide power for the coolant circulating pumps or blowers and probably the diesel generator capacity would also have to be increased.

The weight of the pressure vessel of a natural uranium reactor might be in excess of the maximum lift of the normal fitting-out crane and a reactor would probably have to be built into the hull as part of the ship structure; this arrangement has obvious disadvantages. Attention will have to be given to the problem of maintenance, and in the case of a vessel, should this be necessary, would have to be a major operation and might put the vessel out of service for a considerable time. With a heavy water moderated reactor this operation would be easier as the heavy water could be discharged to a dump tank.

SAFETY

There are many technical features which contribute to the safety of a reactor such as low excess reactivity, large heat capacity and large negative temperature coefficient of reactivity, but unless a system is completely self-stabilizing reliance has to be placed on the control and shut-off rods. Considerable development will be required to produce control and shut-off rod actuating systems which are foolproof, fail safe, and operate under all conditions at sea and are not put out of action by collision or stranding. Not only have the consequences of a pump failure and loss of coolant to be considered but also the loss of sea-water services. When the reactor is shut down heat continues to be generated from the decay of the fission products, starting at about 7 per cent of the power level before shutdown and falling quickly to about 1 per cent after 24 hr. Failure to provide a reliable method of removing this heat might result in melting of the fuel elements. It is advantageous if this heat can be removed by natural circulation of the coolant.

Little experience has yet been gained with the operation of power reactors and a safety philosophy has not yet been fully worked out. The pressurized water and organic liquid reactors have of necessity a large amount of excess reactivity when cold and present designs have a relatively small heat capacity. As a precautionary measure containment is provided for the vapor which might be released following a failure of the primary circuit. With a pressurized water reactor with a primary circuit pressure of 1,500—2,000 psi this is difficult to arrange, and in a merchant ship a massive pressure vessel would be required for this purpose. The primary circuit pressure of an organic liquid reactor is much less and there should be no problem in providing containment.

The low-rated natural uranium reactors now being built in this country are considered to be safe, but nonetheless as a safety precaution are still located away from centers of population: ships must enter ports. It will be rather more difficult to maintain the same standard for advanced designs of power stations with higher heat ratings and for marine reactors. Higher ratings may be achieved by using bundles of small-diameter rods as the fuel elements but there seem to be advantages to be gained if a sufficiently high enrichment can be used, in dispersing the uranium to some extent in a ceramic material such as graphite and in this way raise the maximum temperature at which the fission products are retained in the fuel rods.

Before nuclear-powered merchant ships can be brought into general use international agreements will have to be established to cover the operation of such vessels. International standards of containment, safety factors and operation will have to be agreed to before the use of nuclear power for this application is widespread. The question of insurance is also an important one and the coverage necessary will have to be defined.

CONCLUSIONS

An attempt has been made to give a general review of the present position regarding the application of nuclear power to the propulsion of merchant ships. The prospects are likely to be affected by the shortage of enriched fuel in this country, but the low direct-fuel cost of power from natural uranium reactors may well lead to these being commercially attractive for the propulsion of large ships in the near future, for which powers of the order of 20,000 shp and above are appropriate. It should be noted that some three or four years would probably be required to develop a natural uranium heavy water moderated reactor for this purpose; whether or not such a development takes place in this country may well depend on the prospects for enriched fuel in

the early 1960s. The only power reactor which has so far been developed in this country is the gas-cooled graphite-moderated reactor and should there be any immediate project for a nuclear-powered merchant ship there would be no alternative to this type, probably with enriched fuel.

Although there are many problems affecting the future prospects and many limitations on design likely to be imposed by marine conditions it may be expected that once the commercial attractiveness of nuclear propulsion has been demonstrated progress will be rapid and extend to a wider range of ships.

It must be realized that with the passage of time the cost of nuclear power will certainly come down due to technical advances in the utilization of nuclear fuel, whereas the cost of power from coal and oil will rise. For nuclear power stations, Hinton has recently forecast that by 1990 the cost of nuclear power would be some three-eighths of that produced by coal-fired stations. It appears therefore just a question of time before nuclear propulsion will show to advantage and the British shipbuilding and marine engineering industries are already taking a keen interest and active part in developments, through the collaboration established between B.S.R.A. and the Atomic Energy Authority.

Nuclear power studies reported in the United States for merchant ship application include at least four principal types of reactors. In a study reported by R. J. Gimera, the use of an organic moderated and cooled reactor for powering a tanker was discussed. This plant produces superheated steam at 450 psi and 580° F for the propulsion plant. A supercritical water reactor plant having the possibility of producing steam at 800 psi and 925° F has been discussed in a paper by Fahrner, Farbman, Hemmerle and Sadler. This reactor used water at a pressure of 4000 psia and 1000° F as a reactor coolant. Shackleford and Morrell have reported an investigation of powering a tanker with a boiling water reactor, producing saturated steam at 600 psig and 488° F. A helium-cooled reactor for gas turbine drive of a tanker was reported by C. R. Russel. Helium at about 1300° F and 1000 psia delivered to the turbine is said, in this study, to result in an overall thermal efficiency of over 30 per cent.

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HOLMES F. CROUCH

REGULATORY ASPECTS OF NUCLEAR SHIP SAFETY

THE AUTHOR

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THE advent of fissionable fuel and its application to shipboard propulsion hold promise for a great new era of marine technology ahead. The endurance potential of nuclear fuel means that ships of tomorrow will go farther and faster than they ever could before. But—with this great potential—there are accompanying hazards which should be carefully previewed. Now, to the normal hazards of ship operation there are superimposed the hazards of accidental radiation release.

A "SUPPOSE" ACCIDENT

Although every possible precaution is being taken in the design of nuclear ship reactors to assure that accidents will not happen, in a practical situation there may arise circumstances which could lead to adverse consequences. Nuclear ship accidents are not beyond the realm of possibility. They could happen to either Navy or Merchant nuclear ships.

Suppose, for example, that a nuclear ship is underway in a typical American harbor, weather clear and sea calm. Suppose a sport-fishing boat with a load of passengers carelessly veers into a crossing situation with the nuclear ship. On its other bow, a tug with two barges rounds a bend, having obvious difficulty in managing against the tidal conditions at the time. Towards the stern of the nuclear ship, a 70,000-ton loaded tanker approaches in an overtaking situation. To avoid the sport-fishing boat, the nuclear ship changes course and sounds the appropriate whistle blast. This is misunderstood by the tug which sounds crossing signals, forcing the nuclear ship to back down hard. This causes the nuclear ship to swing broadside to the tanker which is unable to stop or change course because of its deep momentum. Then—crash! The nuclear ship lists over. Her hull is torn open; her reactor shielding tank is punctured; her reactor control-rod housing is demolished: the control rods are jammed. The externally damaged reactor oscillates between excessive power excursions and intermediate shutdown. In the process, some radioactivity is released, but no loss of life is incurred.

As improbable as the accident above may be, questions arise nevertheless: What can be done to protect the health and safety of people against the accidental release of nuclear ship radioactivity? What can be done to bring nuclear ships in line with the conventional safety standards of steam ships and motor vessels? Will special safety regulations help? If so, how should they be formulated and administered? These and other regulatory aspects necessitate mature consideration now, in order to minimize emotional misdirection later.

PRESENT REGULATIONS: NONE

There are no nuclear ship safety regulations at the present time.* Although the Navy, for its ships, has worked out extensive safety inspections and radiation monitoring procedures, and it has sponsored rigorous nuclear training programs for its own personnel, none of these measures is spelled out in the form of published nuclear ship safety criteria. Actually, however, there are advantages to this regulatory void.

* C. R. McCullough, "The Design of Reactor Systems for Safety," *Mechanical Engineering*, March, 1957, pp. 251-252.

In the first place, nuclear ships are still in their experimental and developmental phases. This is true even though there have been announced plans of 75-100 naval reactors during the next eight years.* Reactors succeeding the *Nautilus* already have undergone modifications in design, such as shielding, control rods, fuel elements, etc. Many more technical revisions and design modifications are in the offing before a "standard" nuclear ship reactor comes into being. This is the developmental nature of a complex technology. Accordingly, it would be unwise at this time to bog down nuclear ship research and development with the inflexibilities of administrative regulation. As long as technical talent holds out, it is possible to work out separate safety procedures for each nuclear ship built. This permits modification of safety procedures as technical experience unfolds. Thus, nuclear ships have a distinct regulatory advantage: they can start with a clean slate!

There is a further advantage. That is, there is adequate preparatory time to assimilate the constructive value of including both Navy ships and Merchant ships within the scope of public safety requirements . . . as in the case of aircraft. This facet has not yet come to the forefront. But in reactor circles, it is generally recognized that the operational aspects of reactor safety are analogous to the operation of aircraft and the problems of traffic congestion over airports.† The trend more and more is to require conformance of military aircraft, as well as commercial planes, to those regulations affecting public safety. It would seem that the same all-inclusiveness would apply equally well to nuclear ships. The hazard potentials are the same, regardless of whether radiation should emanate from a Navy ship or from a Merchant ship. Consequently, in preparing the groundwork for nuclear ship regulation all nuclear ships could be considered tentatively as a class. Then, later, special consideration could be granted to each type of nuclear ship depending on its normal peacetime operation.

* J. E. Kenton, "Nuclear Navy Paces U.S. Atomic Industry," *Nucleonics*, July, 1957, pp. 66-71.
† R. H. Graham, "U.S. Reactor Operating History: 1943-1954," *Nucleonics*, October, 1955, pp. 42-45.

THREE HAZARD POTENTIALS

To gain proper perspective for the role of nuclear ship regulation, a review of the fundamental radiation hazard potentials is of interest. Briefly, there are three such hazard potentials when operating a nuclear reactor, namely: (1) the buildup of radioactive fission products, (2) the induced radioactivation of nearby materials, and (3) the propagation of fission gamma rays. (See Figure 1) All of these hazard potentials are natural phenomena of the fission process; one cannot regulate against them.

The hazard potentials increase in magnitude in proportion to the power derived from a reactor and the duration of its operating time. For example, a 60 MW reactor operating for two years represents more of a hazard potential than a similar reactor operating for one year. The quantitative aspects of this can be shown.

Every fuel atom that is fissioned produces two primary fission products. These products are en-

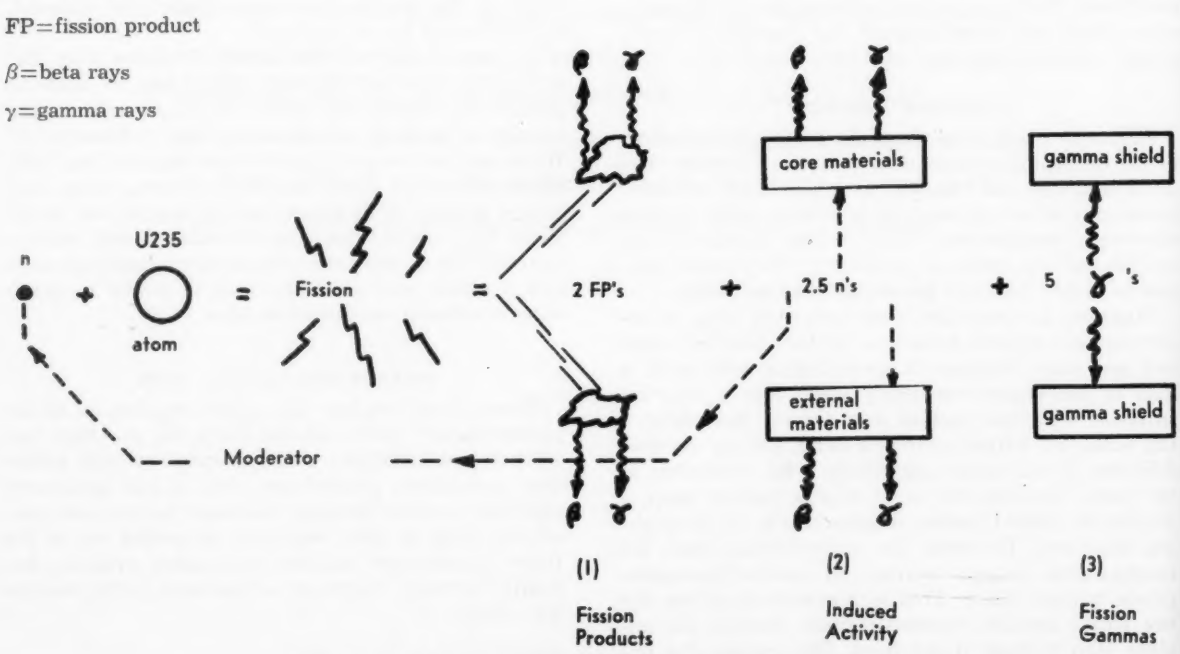

Figure 1. Basic Hazard Potentials From a Typical Fission Event.

tirely new species of matter created by the violent rearrangement of nuclear particles from the fuel. They are radioactive; that is, they disintegrate—usually by the emission of beta and gamma rays—until they reach a stable energy state. There are approximately 80 different primary fragments produced in fission and each decays or disintegrates in a characteristic scheme of its own. Some lose their radioactivity in a short while; others take longer. From a mixed-mean conglomerate of fission products, the hazard potential (H-P) can be approximated by

$$\text{H-P} \approx 8.8\,P[(t_s)^{-0.2} - (t_o + t_s)^{-0.2}] \text{ curies}^*$$

where,

P = reactor power in watts; t_s = time after reactor shutdown (in seconds), and t_o = reactor operating time (in seconds).

Thus, if the operating histories of two reactors were identical (i.e., those terms within the brackets of the equation above), their relative hazard potentials would be directly proportional to their power levels. On the other hand, if the *power levels* of two reactors were the same, and one operates, say, ten times longer than the other, the longer operating reactor would be about 3.5 times more hazardous. This means that two identically-powered nuclear ships would not constitute identical hazard potentials. Much would depend on their operating histories.

Of the approximately 2.5 neutrons produced per fuel atom fissioned, at least one must replenish the original neutron that caused the fission, in order to keep the chain reaction going. A slight excess of this one neutron is needed to increase the power level of the reactor. All other neutrons unavoidably participate in a variety of nonfission events. A fraction are captured by materials in the reactor core (e.g., the reactor shell, grid plates, control rods, coolant, etc.) and the others leak from the core to be captured by external materials, such as biological shielding, auxiliary piping, instrument wiring, nearby rust and dust, etc. Generally speaking—though not in all cases—these nonfission neutrons activate the materials which capture them and thereby induce secondary radioactivity. Each material so activated gives off characteristic beta and gamma rays. The induced activity in *each* species of material can be determined from the relationship

$$A \approx \frac{\phi \Sigma_a W (1 - e^{-\lambda t_o})}{3.7 \times 10^{10}} \text{ curies}^\dagger$$

where,

ϕ = nonfission neutron flux; Σ_a = probability of neutron interaction per unit volume of material; W = weight of species material; λ = radioactive decay constant of species material; and t_o = reactor operating time.

Because of the great variety of materials in a reactor plant, and the diversification of their location and geometry, it is difficult to approximate the accumulated total induced radioactivity. Nevertheless, it is a significant hazard potential though considerably less severe than the buildup of fission products. Induced radioactivity also is a function of reactor operating history (t_o) and its power level (which is proportional to ϕ).

The third hazard potential—fission gammas—is less significant than the foregoing two. The fission gammas are generated only during reactor operation, and in any well designed system the biological shielding would attenuate most of them. Except in rare cases, fission gammas do not induce secondary radioactivity. When the reactor is shut down—either intentionally or accidentally—the fission gammas cease to be a hazard potential. In the case of fission products and induced activity, however, beta and gamma rays continue their emanation long after reactor shutdown.

POSSIBLE CAUSES OF ACCIDENTS

Successful methods have been found for containing and controlling the hazard potentials described above. These potentials become hazards *only* when they are released in an uncontrolled or accidental manner. Despite good engineering practice and conservative reactor design, nuclear accidents can happen. Accordingly, regulatory effort could be devoted to uncovering the probable causes of such accidents, with the prescription of preventive measures against them.

To typify some of the causes of nuclear accidents, consider the accumulation of fission products. These potential hazards, it will be recalled, originate directly from the fissionable fuel itself. As a result, they are concentrated exclusively within the fuel elements of the reactor core. To safely contain these fission products, all fuel elements are cladded or jacketed (see Figure 2). Thus, one might ask: What are the possible ways by which fission products may escape, leak, or diffuse through the cladding materials? If cracks and pin holes develop in the cladding, radioactive fission products obviously would get through. And if temperature conditions were high enough—even though the cladding were free of cracks and pin holes—fission product gases and particulates could actually diffuse through the interstitial spacing of the cladding material atoms. Once outside the fuel elements, the fission products would be picked up and transported by the circulating coolant. The coolant may deposit them external to the reactor core in piping bends, joints, valving, low spots (if particulates) and high spots (if gases).

*1 curie = 3.7 x 10^{10} disintegrations/sec. See T. J. Burnett, "Reactors, Hazard vs Power Level," *Nuclear Science and Engineering*, May, 1957, pp. 382-393.

†Bopp and Sisman, "How to Calculate Gamma Radiation Induced in Reactor Materials," *Nucleonics*, January, 1956, pp. 46-50.

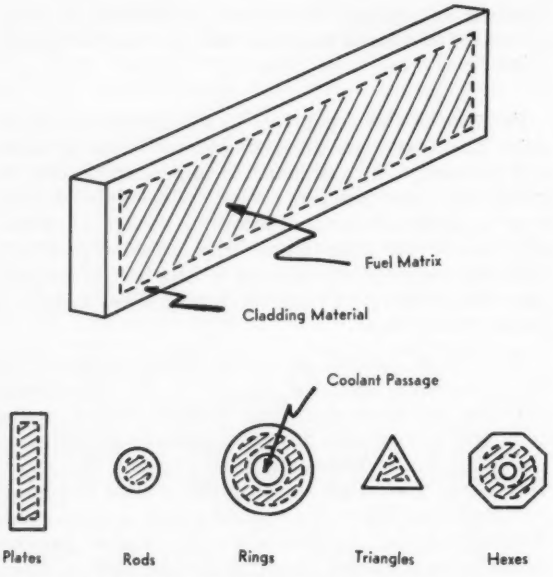

Figure 2. Typical Cladding Shapes for Nuclear Fuel.

There are many ways by which cracks, pin holes, and diffusion trails through cladding materials could develop. For example, there could be:

(1) defective cladding welds and irregularities in cladding thickness;

(2) inhomogeneities of fuel dispersion within the fuel element proper;

(3) pressure oscillations and vibrations set up by the fission and heat removal processes;

(4) warping of fuel elements by internal stresses and the consequent development of hot spots where the coolant flow is restricted;

(5) erosion and abrasion of cladding surfaces by the momentum of coolant flow;

(6) chemical dissolution of cladding constituents with the coolant medium;

(7) neutron activation of the cladding with the consequent atomic transformation to new material nuclei with properties dissimilar to the original cladding;

(8) defects, voids, and impurities in the atomic structure of the cladding material;

. . . and other causes. The above causes comprise the materials category of fuel element accident possibilities. To offset these possibilities, an extensive array of "materials specifications" (i.e., classification of cladding and fuel matrix materials, fabrication techniques, testing procedures, etc.) eventually could be established. The evolution of these specifications would be a tedious and time-consuming matter.*

A further factor influencing fuel element safety pertains to the reactor control rods. These rods are mechanical devices which move in and out of the reactor core to control the excess fuel built into the fuel elements for power operational purposes. These rods usually are two to three times the length of the fuel elements themselves, but they need travel only minute distances to regulate the power level. If these rods are removed too far, or too fast, the reactor power may increase so rapidly that the fuel elements would either melt, burst, or vaporize. The results would be the release of radioactive fission products.

What could cause the control rods to malfunction? There are several possibilities, namely:

(a) inadequate calibration of reactivity "worth" (i.e., excess fuel) in terms of time, position, and relation to other control rods;* (see Figure 3)

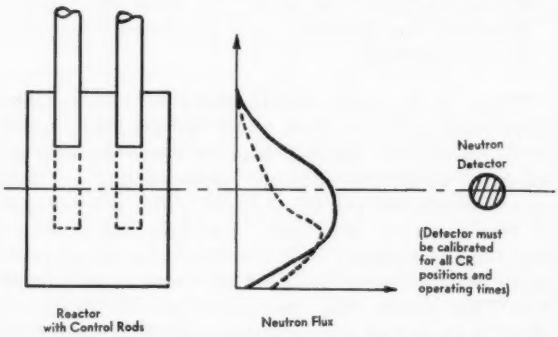

Figure 3. Change of Control Rod "Worth" with Position in Reactor.

(b) long-term exposure to thermal agitation of coolant and radiation from core may induce corrosion, warping, or jamming at guide sleeves and between fuel elements;

(c) electrical and mechanical failures in drive motors, backlash in gear trains, and collections of metallic dust and sludge in hydraulic and pneumatic orifices;

(d) erroneous signals fed to automatic regulating devices due to radiation damage, thermal transients, vibration loads, shock, etc.;

(e) deterioration of neutron-flux and temperature-sensing instruments which display their readings on control board dials and recorders;

and, perhaps the most significant of all control rod accident possibilities . . .

(f) human operator errors, misunderstandings, and carelessness in pushing the wrong buttons, turning the wrong knobs, and watching the wrong dials.

OPERATOR QUALIFICATIONS

To avert reactor accident possibilities due to human shortcomings, the establishment of operator qualifications is important. To illustrate this importance, two examples can be cited, namely: the NRX accident at Chalk River, Canada (December, 1952) and the ERB-1 meltdown at Argonne National Lab-

* H. A. Wagner, "Standardization Problems of a Reactor Designer," *Mechanical Engineering*, March, 1957, pp. 248-250.

* Schultz and Connor, "Power Reactor Calibration," *Nucleonics*, February, 1954, pp. 8-12.

oratory (November, 1955).* In the NRX case, the reactor was in a safely shut down condition. Yet, due to a "misunderstanding," the control rods were suddenly pulled out with the result that a number of the fuel elements were vaporized. In the EBR-1 case, an experiment on a high power excursion was in process wherein the power was doubling every 0.27 seconds. Special fast-acting shutdown rods were to be used upon visual signal from short time-constant instruments. Upon receiving the proper signal, the reactor operator first pressed the wrong button, then the right one. The delay was not more than two seconds, but it was sufficient to cause reactor runaway . . . and meltdown.

Those who design and manage the operation of nuclear reactors have long been aware of the importance of human operator precautions in the start-up and control of reactors. In many cases a "procedure panel" is used, which is a series of lights which come on successively as the various conditions are satisfied for safe warmup, startup, and steamup. These lights are an aid to operators who must sequentially push buttons, energize relays, open valves, turn knobs, watch meters, check recorders, listen to annunciators, etc. All of these procedures require technical competence and discretion in order to assure that the reactor is in a safe status at all times. Accordingly, regulatory effort towards the establishment of minimum operator qualifications and examination standards would be pertinent.

All important operational information is channeled to the reactor console which is physically larger in size and greater in complexity than the instrument panel in the cockpit of large aircraft. Indeed, reactor operators today need to be instrumentation specialists.† Neutron flux measurements have to be read . . . on three different ranges of instruments;** control rod positions have to be noted (on separate indicators for each rod); temperature, pressure, and flow rates of reactor coolant have to be known; fuel element failure indicators have to be observed; temperature and radiation in shielding tanks have to be recorded; and power to auxiliary pumps, motors, pneumatics, and electronic equipment has to be on. All in all, over 100 instruments displaying information sensed from more than 1000 points throughout the reactor plant require the attention of human operators. Not only must the operators read these instruments—the correct scales and in correct units—they should know something of the technical principle on which the various instruments work, and the limitations, inaccuracies, and reliability thereof. Instrument failures do occur—sometimes too frequently—so that human operators must always be alert to detect these failures and to take corrective action. To do this properly, adequate training is needed.

One way to provide the necessary operator training is through the use of reactor "simulators." A simulator console consists of meters, recorders, knobs, and switches which are replicas of those on the actual reactor console itself. These simulator instruments, however, are actuated by servo-components and computers which can be designed to simulate virtually any operational phenomenon of a live reactor. A very high degree of realism can be achieved.* A separately mounted panel enables an instructor to inject various trouble conditions and emergencies. Trainee performance can be checked and valuable experience can be gained without jeopardizing the safety of the reactor plant and the safety of the operators themselves.

But there can be no all-purpose simulator: each is designed to match the characteristics of one particular type of reactor plant. An operator checked out on one type of simulator—say, one simulating a pressurized water, heterogeneous fueled reactor—would not, per se, be qualified to operate another type of reactor, say, a gas-cooled, solid homogenous system. The situation is analogous to the checkout of pilots in aircraft. Each power-plant has some similarities to others, but differences in fundamental design spell major differences in performance capability, response to control, and the magnitude of the hazards involved. Hence, regulatory standards should differentiate between operator qualifications so that an operator qualified for one class of reactors is not given carte blanche license to operate all reactors.

THE RISKS OF MOBILITY

The accident possibilities above apply to stationary nuclear reactors as well as to nuclear ships. But the risks are greater in the case of nuclear ships. Whereas stationary plants are located at remote areas determined by a rule-of-thumb exclusion radius,† nuclear ships—by their nature of being ships—move about in harbors and are exposed to maritime traffic. The possibility of a collision is real. This does not mean that special Rules-of-the-Road privileges should be conferred upon nuclear ships, nor that they should be prohibited from normal berthing, docking, and anchorage maneuvers.** The risk of ship collision *does* mean, however, that special design attention should be given to nuclear ship reactors and this is where safety regulation could lead the way.

To date, reactor design technology has evolved strictly from the concepts of stationary reactors where accident possibilities could originate largely within the reactor plant itself. External accident

* See accounts in *Nucleonics:* NRX—March, 1953, p. 70, EBR-1—June, 1956, p. 35.
† J. M. Harper, "Reactor Operation," *Nucleonics,* June, 1953, pp. 35-40. See also D. S. Toomb, Jr., "Instrumentation and Controls for HRT," *Nucleonics,* February, 1957, pp. 48-52.
** Neutron measuring instruments for reactor startup include: (1) source range: 10-10 to 10-8; (2) period range: 10-7 to 10-3; and (3) power range: 10-2 to full power.

* Franz and Alliston "PWR Training Simulator," *Nucleonics,* May, 1957, pp. 80-83.
† Exclusion radius in miles=0.01 $\sqrt{\text{Power in kw}}$; e.g.: a 60 MW reactor would invoke an exclusion distance of about 2.5 miles.
** Actually, it would be helpful to adopt special flags, lights, and sound signals to identify nuclear ships to others . . . without conferring any special right-of-way.

possibilities, such as ship collisions, have not yet significantly influenced reactor design. For example, shipboard reactors utilize the control rod concepts of their land-based prototypes. These rods (see Figure 4) are long, slender shafts extending from the lower part of the reactor core through the upper part of the reactor shell (or vice versa). The upper and lower guide clearances are minute and each shaft alignment is precise. Assuming a sharp, nonfatal external collision of some kind, it is conceivable that the control rods could be bent, twisted, or disaligned just enough to prohibit their operation. As another example, ship type reactors, so far, are pressurized water reactors (up to 2000 psia) with reactor shells somewhere between 6 and 9 inches thick. To the casual observer, this is an impregnable armor in itself. But all of this metal is pretty hot, thermally speaking. Just a few bucketsful of ambient temperature seawater (such as could pour in from a collision) and the resulting thermal shocks would telegraph many cracks throughout the reactor shell. The purpose of citing these two examples is to point out that nuclear ships invite external risks which have not yet been fully explored in reactor design. Sound regulation could stimulate the closing of this void.

As nuclear ships move from harbors to the open sea, other risks accrue. These are largely of a long-term environmental nature . . . storms, poundings, and saline atmospheres. It should be anticipated that these environmental adversities—sooner or later—could make their impact on the seaworthiness of reactor designs. This would be particularly true of reactor instrumentation, radiation monitoring devices, and the human engineering (and automation) of reactor and auxiliary controls. Instruments which are desirably sensitive to neutron fluxes, temperatures, flow rates, radiation, etc., also are *un*desirably sensitive to vibrations, corrosion, accelerations, fungus, etc. Accordingly, regulatory effort could establish "environmental specifications" and the stipulation of testing procedures for nuclear ship equipment.

There are still further risks when nuclear ships move from port to port, country to country. Because of popular misconceptions concerning nuclear hazard potentials and the unreasoned fear thereof,* restrictive regulation would be imposed in every port visited—national as well as international. Every port authority has jurisdiction over its waters and few opportunities would be missed to exercise port control over nuclear ships. For example, shim control rods (which negate the major percentage of excess fuel built into a reactor) might be locked and sealed by port inspectors who would permit only the use of regulating rods for small changes in power level. All radiation waste disposal outlets (i.e., stack exhausts, underwater discharges, etc.) might be plugged and monitored around-the-clock. Docking might be limited to remote assigned areas and movement in the harbor might be limited to daylight only. These restrictions would be a serious imposition indeed, but in the interests of absolute safety, it is conceivable that they could be applied.

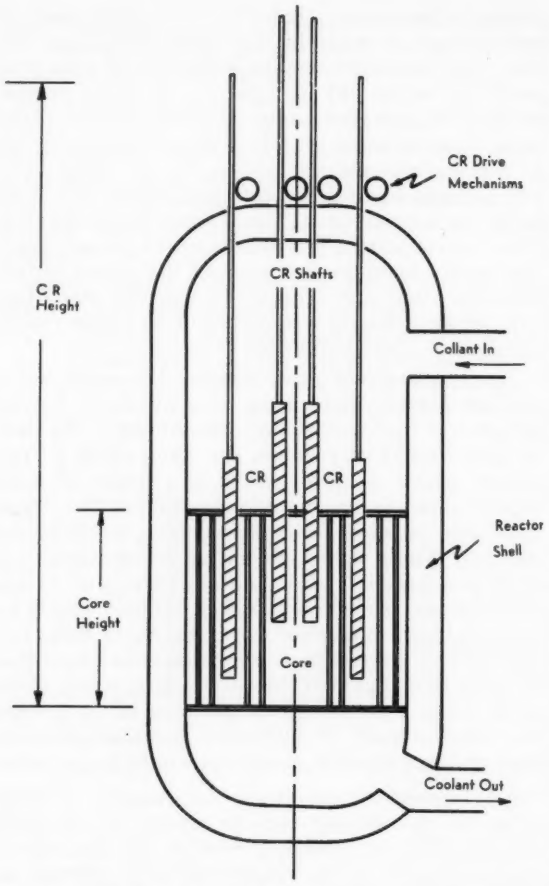

Figure 4. Typical "Lengthiness" of Reactor Control Rods.

COORDINATION OF SAFEGUARDS

In addition to regulations imposed by port authorities, nuclear ships could be plagued by regulations from operating departments, municipal bodies, state bureaus, Federal agencies (e.g., the AEC, Maritime Administration, Navy, Coast Guard, etc.) and international commissions. Each could attempt to define the objectives of safety in its own terms with the possibility that there could arise conflicts, overlaps, and oversights in vital areas. No regulatory body—with cognizance over any phase of nuclear ship operation—wants to have the public finger of scorn pointed at it, should there ever be a nuclear ship accident. As a consequences, each agency would be motivated by the innate desire to protect itself and one way of doing this would be to prescribe an abundance of regulation, just to be on record. To

* "Reactor Hazards Predictable: Great Need for Public to be Educated," *Nucleonics*, November, 1953, p. 80.

those on the technical side of nuclear ship development, this possibility casts a forbidding gloom.

It would appear desirable—even at this time—to, somehow, channel the endeavors of regulatory interests toward the more constructive benefits of technical safeguards. As a pattern which might be followed, there is now in being an Advisory Committee (to the AEC) on Reactor Safeguards.* This committee is staffed with scientists, engineers, and administrators of private industry, Government, and educational institutions. All members are leading men in their respective fields. At the present time, however, the marine field is not too well represented. Presumably, as the number of nuclear ships increases, so would the number of marine representatives on the safeguards committee increase. Conceivably, then, such a committee would enjoy the necessary balance and blend of experience to pass judgment on the safety aspects of every type of nuclear ship.

Unfortunately, the above committee has one basic limitation: it is an approval-type committee only. That is, it accepts, modifies, or rejects those "hazards reports" submitted to it. It does *not* create safety regulations nor does it make any particular effort to coordinate those safeguards proposed. This is not the function of the committee, nor was it intended to be.

Insofar as nuclear ship safety is concerned, a case could be made for a counterpart advisory committee to *create* safety regulations and safety standards, and to *coordinate* all regulatory efforts toward a common goal. It is not yet clear whether this could be done on the same basis as the safeguards committee above. It may be that a nuclear engineering and management consulting type of organization could best serve the desired creative and coordinative functions. It is possible that such an organization could establish itself as a specialist in nuclear ship safety by working closely with pertinent regulatory interests and technical societies. The ultimate goal would be the development of a nuclear ship safety "bible" from which applicable sections could be extracted in whole or in part for enforcement by existing regulatory agencies.† The point here is *not* to create another regulatory or quasi-judicial agency, but to provide a coordinating medium for the benefit of existing agencies. Such an organization need not have regulatory powers, and it could be privately managed.

THE LAST FRONTIER

Except in the future advent of space ships, nuclear ships represent the last frontier for which it is possible to develop sound regulation truly beneficial to the progress of mankind. Other forms of enterprise subject to regulation have experienced technical retardation and deleterious effects from too much regulation written with too much legalistic jargon—difficult to read and equally difficult to enforce. Now, at least, is an opportunity to start with a clean slate and create a regulatory context that is technically sound, readably clear, and philosophically direct. As naive as this may appear, there are ways in which this could be done.

The fundamental purpose of nuclear ship regulation is threefold, namely: (1) to prevent specific accidents, (2) to disseminate safety experience and technical data, and (3) to induce compliance with minimum standards. To achieve this purpose, each regulation could be prefaced with its objective, that is, a statement of the type of accident it is supposed to prevent. This could be followed by a discussion of the technical principles involved, with the necessary backup, such as figures, curves, calculations, footnotes, etc. Materials and environmental specifications, refueling and decontamination procedures, and other standards could be formulated concisely with suitable tables, diagrams, and checklists. Significant nuclear accidents and near-accidents of the past could be appendaged as a documentation to newcomers . . . and as a reminder to oldtimers. The manner of written presentation could be the composite of a technical book, application brochure, and informational manual. In short, an entire "fresh approach" to regulatory content could be developed.

It is recognized, of course, that the gathering, organizing, and written preparation of the material above represents a *major* undertaking. It could not be accomplished in one year or two, but on the order of five years to ten. It would take this long to set up a coordinating medium and to establish the necessary liaison between contributory and regulatory interests. The Navy, private contractors, professional societies, trade unions, educational institutions, Government agencies, port authorities, ship operators, mariners, and others participating in nuclear ship development would have to be contacted and their suggestions and comments solicited. This effort need encompass only those safety matters which are fundamentally nuclear in nature. The conventional aspects of ship safety regulation—for both nuclear and non-nuclear ships—need not be considered. This would allow treatment of nuclear safety as a separate nautical entity.

* See *Nucleonics*, January, 1954, p. 9. Also, "Licensing Nuclear Facilities," Rep. W. Sterling Cole, Joint Committee on Atomic Energy, *Nucleonics*, February, 1955, pp. 26-29.

† A precedent example: the Nautical Rules of the Road. Here, a single compilation gives the details of international, national, and local regulations.

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A combined gas turbine and steam turbine power plant will operate in a 15,000 KW installation being constructed in Warwick, Georgia. The base load is to be carried by the steam plant, consisting of a 12,500 KW impulse turbine-generator combination, operating from 600 psig, 825° F steam at the throttle. For peak load, a gas turbine-generator combination will be started up. Since the gas turbine exhaust contains about 16 per cent oxygen and has a temperature of about 840° F, it is suitable for combustion air for the boiler. Consequently, at high powers, fire-box air comes from this source. However, since more gas turbine exhaust is available than is required by the boiler, the remainder is combined with the boiler stack gas and passes through the economizer. The resulting improvement in efficiency is brought about with very little added complexity in arrangement.

—from "Mechanical Engineering"
January 1958

"U. S. NAVAL INSTITUTE PROCEEDINGS"

TOWARD A NUCLEAR-POWERED SEAPLANE

ACKNOWLEDGEMENT

Commander Arthur D. Struble, USN, who is currently Project Officer on Nuclear Seaplanes, Bureau of Aeronautics, is the author of this article. It was published in the November 1957 edition of "U. S. Naval Institute Proceedings." *Copyright 1957, U. S. Naval Institute.*

Following Operation Alert, in which fifty-eight American cities were subjected to theoretical nuclear and thermonuclear attack, Federal Civil Defense Administrator Val Peterson reported: "Almost one out of three persons in the United States would have been killed, injured, or made homeless. . . ." To help preclude such a national disaster, the Navy is developing effective weapons for the defense of this country. One such weapon is the nuclear-powered seaplane.

The inherent advantages of the seaplane as a weapon lie in the opportunities that it offers for mobility and dispersion. In this age of thermonuclear weapons, the possibility of total-force destruction from sudden enemy attack cannot be ignored. By utilizing the mobility and dispersion capabilities of water-based aircraft, the Navy can reduce this threat to our country. For example, the use of water-based aircraft will permit us to select a battleground far from our own shores. As the Secretary of the Navy put it in speaking of the new seaplane strategy: "If you want to romance its possibilities, look at a world map and imagine the numberless bases where a seaplane can operate. The oceans and seas will be its bases. These waterfields will cost nothing. They will require little maintenance and their use will pose no problem of sovereignty."

With nuclear-powered aircraft, not only will the vast ocean areas become runways but the striking force can be concentrated or dispersed quickly. With the range made possible for seaplanes by the use of nuclear fuel, the mobile bases supporting them can be moved farther back and spaced farther apart, thus decreasing the vulnerability of the bases to enemy attack. Furthermore, the nuclear-powered aircraft can find weather and sea conditions suitable for its operations since an extra 1,000 miles of cruising would make relatively little difference.

Nuclear aircraft propulsion, which promises so much when coupled with the mobility and versatility of the seaplane, is still in its developmental phase. Research in this field dates only from the end of World War II. Aircraft propulsion experts, recognizing that the high rate of fuel consumption was a major limitation of the jet engine, looked to nuclear energy as a prime heat source. A joint Navy-Air Force project called "NEPA" (Nuclear Energy for the Propulsion of Aircraft) was established to investigate the feasibility of airborne reactor propulsion. Since initially it appeared that a nuclear-powered aircraft would involve a large, heavy system, the project held major interest for the Air Force. With the advent of the jet-powered seaplane, however, the Navy has increasingly turned its attention to the development of a nuclear-powered seaplane.

Since May, 1953, when Convair and Martin received Navy contracts to study the practicability of adapting nuclear propulsion to existing flying boats, significant progress has been made. Research has been guided by the requirements of two basic missions of naval aircraft—one, a long-range, high performance mission with the objective of striking naval targets and supplementing the Navy's attack carrier striking forces; the other, a lower performance mission such as that involved in airborne early warning and patrol activities. Currently, the Navy is interested in the development of a nuclear-powered aircraft of relatively low power and performance which will be especially suited to primary naval misssions.

The Navy's patrol, anti-submarine warfare, attack, and airborne early warning missions require aircraft with long endurance and/or range capabilities. Nuclear-powered aircraft will satisfy these requirements. The *Nautilus*, the first atomic-powered submarine, has already demonstrated the advantages of nuclear propulsion by cruising thousands of miles without refueling.

Aside from mission considerations, there are several reasons why it seems desirable to adapt nuclear

propulsion to a seaplane. First, 10,000-foot or even 20,000-foot water runways are readily available to accommodate waterborne, atomic-powered aircraft. In view of the negligible weight consumption of fuel by the nuclear power plant, these aircraft will have a landing weight essentially equal to their take-off weight. Water runways with no known weight absorption ceiling, therefore, offer a significant advantage for nuclear-powered aircraft. Secondly, a seaplane offers safety advantages during the experimental phases of nuclear power plant development. By confining flights to ocean areas, the radiation and contamination hazards to populated and industrial areas can be reduced. Furthermore, the landings and take-offs will take place over water, thereby isolating the most frequent casualty flight phases. Finally, current and projected developments in seaplane design indicate that water-based aircraft are well suited for nuclear propulsion.

Since water clearance for the propeller-driven seaplane involves bulky, deep hull sections, gull wings, or pylon-mounted wings or engines, this type of aircraft has high aerodynamic drag values which seriously limit its high-speed capability. However, the adoption of the jet engine and aggressive research on seaplane design during the last ten years has paid off. In 1952, Convair's F2Y interceptor, known as the Sea Dart, demonstrated the success of some of these developments in a configuration which combined the delta wing and hyrdo-ski. Other seaplane hull-wing configurations, which involve no sacrifice in seaworthiness or water performance, are aerodynamically competitive with the fuselage-wing configurations of the most advanced gas-turbine land planes. Seaplane speeds of over 600 miles-per-hour have already been demonstrated, and studies of seaplanes operating at speeds above Mach 1 are indeed promising. It may be concluded, then, that the airframe problem for a nuclear-powered seaplane can be solved. The Convair F2Y fighter, the Convair R3Y attack transport, and the Martin heavy attack P6M are cases in point.

The problems of developing a nuclear engine suitable for a seaplane are extremely complex. Basically, the application of nuclear power to aircraft propulsion involve the conversion of reactor heat into mechanical thrust. Therefore, any nuclear-propelled aircraft must incorporate a reactor and some form of a thrust-producing heat engine. A major problem results from the difficulties of providing these essentials within the weight limitations of an aircraft. A measure of the task involved is provided by a statement of Rear Admiral J. S. Russell, Chief of the Bureau of Aeornautics, who pointed out: "The nuclear submarine works with values of 170 to 175 pounds per horsepower while the nuclear seaplane must achieve a value of 4." This problem may be solved, however, by employing propulsion machinery very similar to that used in current turbine-powered aircraft. The major departure from existing engine designs would be the addition of the nuclear heat through a heat exchanger instead of the conventional burner cans.

The specific nuclear power plant configuration chosen for the Navy's purposes, naturally, must meet the operational requirements which will be imposed upon it. The power plant must provide the capability of conducting long missions from sea bases for sustained periods of time without fuel re-supply. It follows, then, that the reactor must either stay in the airplane for the full operational period, or, if it must be removed, it must be easily and quickly removable.

If the reactor is to remain in the aircraft, it must be capable of being restarted regardless of the time that has elapsed since shutdown. Since some reactor designs build up Xenon poisoning to an extent that precludes restarting from a short time after shutdown until the poisoning has been transmuted to other elements, control systems designers face a real challenge.

There is a comparable challenge for reactor and airframe designers in providing a means of easily removing the reactor from the airframe. Because sizeable quantities of heat are generated even when the reactor is not running, the reactor will melt unless it is continuously cooled. Therefore, a heavy burden is placed on engineers responsible for power plant installation and handling. A typical removal operation, for example, would involve: disconnecting heat transfer lines while maintaining reactor coolant flow, releasing structural attachments between reactor, reactor shield, and airframe, and hoisting or lowering an object of considerable size and weight while maintaining a continuous flow of reactor coolant. Whether the reactor is installed for extended periods of time or is removed at will at an advanced base, the attendant difficulties will be major ones. Obviously, unscheduled maintenance must be held to a minimum, and this requirement calls for a high degree of component reliability.

In addition to the development design problems already mentioned, there are numerous others which call for extensive research and development effort. Take, for example, the question of whether solid or liquid nuclear fuel should be employed. In solid-fueled reactors, it is necessary to insure against fuel element failure over a given period of operation. To provide reliable fuel elements, accurate analysis of thermal stresses and careful allowance for differential thermal expansion must be made. To obtain propulsive efficiency and good aircraft performance, the highest possible fuel element temperature must be insured. For this reason, high temperature metals and ceramics must be exploited to their fullest. If liquid nuclear fuels are used, thermal stresses and differential thermal expansion are again troublesome problems in radiator design. Also, liquid metal and container reactions must be satisfied at very high temperatures.

Despite technological difficulties which defy description in an article of this length, significant prog-

ress has been made in the development of a nuclear power plant. According to the Atomic Energy Commission's Admiral Lewis Strauss, an experimental aircraft nuclear reactor developed by General Electric has successfully powered a turbojet engine. The event took place in January, 1956, at the AEC's National Reactor Testing Station in Idaho. More ambitious tests are now in progress.

Having outlined design problems and progress in the development of an airframe and nuclear power plant for a seaplane, it is possible to consider some of the design difficulties that must be overcome in putting the two together. Power plant installation considerations for a nuclear-powered aircraft differ in three basic ways from those for chemically-powered aircraft. First, because of the radiation hazard, remote power plant inspection and handling must be provided. Second, access doors must be adequate for a very large package composed of the radioactive engine and its components. Third, some structural penalty is exacted by the concentrated weight of shields for the reactor and crew. The latter problem is a complicated one. The aircraft designer must have the crew radiation tolerance established prior to design because the degree of tolerance has a direct bearing on the weight of the shields that must be provided. The degree of tolerance, however, is a medical rather than engineering problem.

The allowable reactor radiation dose which a flight crew can tolerate has been the subject of much research. It has been established that nuclear radiation causes immediate effects (i.e., within thirty days) and latent or long-time effects. To produce immediate effects, such as nausea, vomiting, and loss of hair, fairly large doses are required. The amount is in the vicinity of 75 to 100 REM, where "REM" is the radiation dose unit of measure. Long-range effects which must be considered in designing a nuclear-powered seaplane are: degradation of performance, incidence of cataracts and leukemia, shortening of life span, and genetic mutations.

Medical evidence is encouraging about the possibilities of avoiding the undesirable effects of radiation doses. In the cases of degradation of performance and the incidence of cataracts and leukemia, there appears to be a threshold dose. By restricting radiation below this level, we can totally avoid these effects. As far as the shortening of the life span and genetic effects are concerned, however, the effects of radiation apparently cannot be reduced to zero. This fact raises the question of how large these effects can become and still be considered acceptable.

On the basis of investigations conducted on the shortening of life due to radiation, it appears that this danger may be less than that from other hazards, occupational and otherwise, which are readily accepted today.

Although a naval aviator's career as a pilot may last eighteen to twenty years, only five or six years of this time would probably involve operation of a nuclear-powered aircraft. Normal flight training, squadron duty, postgraduate school, and the usual tours of shore duty would occupy the remainder of the time. Since the National Academy of Science suggests that a total accumulated radiation does not exceed fifty REM at age thirty and one hundred REM at age forty, it appears that dose rates which must be considered in aircraft design can be increased from what was previously considered acceptable. A corresponding decrease in shield weights will therefore be possible. Career programming can then be used to insure that a pilot operating nuclear-powered aircraft will not have received a total accumulated dose of more than ninety REM by age forty. Thus, a margin of ten REM is left for background radiation and medical X-rays.

The genetic effects of radiation doses remain to be finally determined. At present the indications are that radiation-produced genetic mutations can be rendered negligible in comparison with the current national average of about one in 25.

Within the framework of biological requirements, the major problem in shielding an aircraft is the attainment of a minimum weight for a fixed radiation dose rate. When the power and speed requirements of an aircraft are those of antisubmarine, early warning, and patrol missions, a large and heavy airplane is acceptable. Under these conditions, a bulky and heavy near-unit shield can be used with the nuclear power plant. To reduce deadweight for high performance aircraft, however, a divided shield has been found necessary.

By dividing the shielding between the reactor and the crew compartment, the aircraft's structural weight, performance, and stability are affected. The greater the weight of the shielding in the crew compartment, the greater will be the structural weight required to carry this load. This fact is especially critical in a hull-type seaplane since the bow landing load factors due to vertical and pitching accelerations are as high as twelve to sixteen "g" in the vicinity of the crew compartment. Furthermore, the stability of the airplane on the water and the yaw stability in flight can be affected by a large mass concentration such as the crew shield. Shield division also affects the speeds that can be attained by the aircraft. The greater the amount of shielding around the reactor, the higher the thickness ratio of the fuselage must be. The result is an increased drag. For instance, adding one foot of shielding on a reactor installed in a 140-foot-long fuselage will increase the airplane's drag approximately five per cent at Mach 1.4.

Another problem of shielding is the choice of shielding materials. The material chosen must not only be a good radiation shield, but it also must possess characteristics that will permit its fabrication into complex shapes with due allowance for thermal expansion, method of support, and manner of removal.

Assuming that a high performance aircraft can be designed with a divided shield so that radiation doses

can be kept within acceptable limits for the crew, the problem of radiation damage to materials still remains. Many of the components used in aircraft today, although developed to a high degree of reliability, may require modification for use in a nuclear-powered aircraft. For example, electronic instrumentation and control components involving capacitors, resistors and micro-switches contain plastics and other organic materials. Unfortunately, organic materials are notoriously susceptible to damage by nuclear radiation. Materials such as leather, rubber, lubricants and hydraulic fluid, which are now used in engine systems, are organic and therefore also subject to radiation damage. If all of the aircraft equipment and structure could be located directly behind the crew compartment, the radiation damage problem would not be very severe. Such a solution, however, is a physical and practical impossibility. The only alternative is to analyze each system and structure in the light of its specific radiation environment and thus obtain an accurate scale of the severity of the problem in each instance.

Since the problem of radiation damage to materials results from the shield division necessary in high-performance aircraft, aircraft for low-performance missions should experience relatively few difficulties on this score. In the high-performance aircraft a compromise must prevail. This compromise must be consistent with acceptable crew radiation doses, materials radiation damage, and performance requirements for the aircraft.

Once all these difficulties are overcome—as they will be eventually—the nuclear-powered seaplane will have an essentially unlimited range potential. The limiting factor will then be the endurance of the crew. Therefore, crew facilities pose major design problems, especially in the case of attack-type aircraft. Factors which must be taken into consideration in determining the configuration of the crew compartment include: number of crewmen required (which is a function of the mission), the space that must be provided for each man, and the equipment that each man will operate. Other important considerations are the allowable crew radiation dose, type of escape device, and vision requirements. All of these factors must be blended into a design of minimum weight for optimum performance of crew and aircraft considered as a unit.

A seaplane with an acceptable configuration has already been developed on an experimental basis. Speaking of the P6M Sea Master with its speed in the vicinity of 600 miles per hour, Vice Admiral T. S. Combs said in April, 1956: "This type plane seems ideally suited for eventual nuclear propulsion due to its size and configuration combined with the numerous take-off and landing areas that water provides." It seems obvious, then, that adequate shielding to protect flight crews can be carried in planes, approximating the P6M, rather than huge, slow, and ungainly bombers.

The nuclear-powered seaplane finally adopted must satisfy the requirements of its military employment. The flexibility exhibited by a submarine refueling a seaplane on the open ocean is the kind of operation desired in the nuclear support concept. The seaplane must be capable of operating from a mobile base, whose movements will keep the enemy guessing. The basing concept envisions a system which will combine a sustained strike capability mounted from the sea with minimum vulnerability and low total costs.

In the case of nuclear-powered aircraft, radiation complicates the servicing and handling problems that will be encountered in making this concept workable. In the handling operation, shield augmentation may have to be added to lower the radiation levels. Aircraft returning from a mission will be radioactively "hot" and, before servicing or maintenance can be performed, additional shielding must be placed around the reactor. Such a shield may be in the form of a liquid, such as sea water, which is pumped aboard through lines that are remotely connected to the aircraft. In addition, a substantial overhead structure will be required to lift the power plant, and provision must be made for guiding the reactor out of the aircraft without swaying which might seriously damage the airframe.

Other operational problems involve refueling and remote systems check-out. Fuel life has definite limits and reactor time is accumulated quickly in long-range Navy missions. Therefore, facilities must be provided for renewing the nuclear fuel. Replacing the complete power package or returning the aircraft to its home base are two possible answers. To minimize the maintenance crew's exposure to residual radiation in the aircraft, remote systems check-out may be required. A system similar to that employed in missiles can be used. It involves plugging cables into the aircraft and checking out electrical and electronic systems from remote locations.

Special equipment will be required to service nuclear power plants. A radiation "hot engine" test stand, capable of operating the entire nuclear power plant at full power on the ground must be provided. A "mating" station will be required to accomplish the remote "mating" and "demating" of the nuclear power plant. Contact maintenance of the reactor will not be possible. Therefore, an engine "hot shop," properly equipped to perform all maintenance and overhaul procedures without endangering personnel, is necessary.

Obviously, the special requirements involved in servicing a nuclear-powered seaplane affect mobility. Therefore, two types of support appear to be desirable—a highly mobile strike base and a highly efficient maintenance base. Logistic air and logistic submarines have been suggested for the mobile strike bases. Various barge and ship tenders have been proposed to handle the maintenance sea base.

A developmental layout must provide for servicing nuclear-powered seaplanes at a shore station. Such a station must be capable of bringing the planes onto

the beach, augmenting the shield, "mating" it for removal of the power plant, providing "hot cell" maintenance of the power plant, isolation of nuclear engine run-up stands, and suitable areas for "remating" and flight preparation. The site must also include a "cold area" for non-nuclear operation of seaplanes.

The preceding discussion has enumerated many of the problems and major developments involved in achieving a militarily significant, nuclear-powered seaplane weapons system. Progress is being made. When a nuclear power plant meeting the Navy's requirements can be successfully adapted to a suitable airframe, the resulting product will be integrated into a weapons system. The elements of dispersion, mobility, and employment of small units—so necessary in this era of guided missiles and atomic weapons—can be achieved. With the nuclear-powered seaplane, the Navy will not only have the capability of countering surprise enemy air attacks far from our shores but also of striking far into the enemy domain to destroy the submarine at its source. Seaplane fuel logistic demands will be greatly reduced, and the ability to deliver a sustained succession of attacks from mobile, dispersed sea bases will be greatly increased. The Navy's nuclear-powered seaplane clearly has a major potential in the national defense complex of the United States.

In an address given at the U. S. Naval Postgraduate School, Dr. Ernest Stuhlinger described an electric propulsion system for space travel application. In this system the velocity of exhaust particles is produced by electric fields rather than by chemical reaction as in a jet or rocket engine. Dr. Stuhlinger noted that in this scheme the amount of energy which can be imparted to a mass of exhaust material is much higher than that which can be imparted to the same mass by chemical reaction. Further, electric fields may be able to direct the particles so that contact with surfaces of the motor is avoided, thus eliminating a high temperature problem with thrust chamber materials. Such a system requires a method of ionization of the propellant material, a primary power source for creation of the electric fields, and a suitably designed thrust chamber. It appears that, while such a system has many advantages, its thrust level would restrict its use to outer space, since it is doubtful that it could overcome gravity forces.

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DESIGN OF AIR FRAMES FOR NUCLEAR POWER

ACKNOWLEDGEMENT

This article is based on a paper presented at the Institute of Aeronautical Sciences, Los Angeles Section Dinner Meeting on 23 May 1957. The authors are Clarence L. Johnson, Vice-President for Research and Development of Lockheed Aircraft Corporation, and F. A. Cleveland, Preliminary Design Division Engineer, in the Georgia Division of the same corporation. The article was published in the June 1957 edition of "Aeronautical Engineering Review."

INTRODUCTION

With the increasing activity in the field of nuclear power for aircraft, it seems in order to discuss some of the technical features and problems connected with aircraft so powered. Naturally, security limits will prevent extremely detailed presentations on many aspects of design features of nuclear-powered aircraft although every year makes the feasibility of the type more and more a certainty. Many problems which seemed insurmountable a few years ago have proved to be of a rather minor nature or nonexistent; others, unexpected, have appeared.

The use of nuclear power is of great interest to the aircraft designer because it provides a means for giving the airplane nearly infinite range, to all intents and purposes. After a half century of striving to make aircraft carry reasonable loads farther and farther, the advent of a type of power plant that will solve the range problem is of the utmost importance. To be able to base military aircraft in the United States and still have a striking power any place in the world is a goal worth striving for. The tremendous implications in the elimination of foreign bases, with the great savings in cost to the taxpayer, are a great factor in encouraging work on the nuclear aircraft. We are reaching the limit of range with our conventional power plants and are having to resort to air-to-air refueling procedures to obtain reasonably acceptable radii of operation.

The majority of the papers which have been written to date on the application of nuclear power to aircraft have dealt almost exclusively with the power plant itself, only cursorily with the air frame. Those of Kalitinsky, Leverett, and Silverstein were focused on the inherent problems involved in perfecting an airborne reactor-engine propulsion unit; the first two of these were somewhat concerned with the feasibility of creating such a power plant *at all* in a practical form. Hibbard's address to the Air Force Association in the spring of 1954 dealt more with integrated airframe—power-plant aspects of nuclear-powered airplanes but, of necessity, fairly briefly.

It is the intent of this paper to explore the nuclear-powered airplane almost exclusively from the viewpoint of the air-frame designer. It is hoped that such an examination will bring to light the real impact of the new propulsion concept by revealing the differences occasioned in the air-frame design and by casting them in terms of advantages, or disadvantages, in the design of a useful air frame. It appears that the strategic bomber, by requiring both high speed and great endurance and because of the inherent low-altitude potential advantages over similar chemical airplanes, will be the first candidate for a nuclear power plant.

We will eliminate chemical augmentation as a significant feature of the airplane operation mainly to keep the discussion more straightforward. We are thus discussing only the all-nuclear airplane with the exception that some chemical fuel is carried for takeoff and landing go-arounds.

As currently proposed (Figure 1), most of the nuclear power plants are large and clumsy, even without considering the shielding required for personnel safety. The nuclear power plant in its early form is inefficient primarily because of the low temperature limits of the operating cycles. These limits are set by the ability of current materials to stand

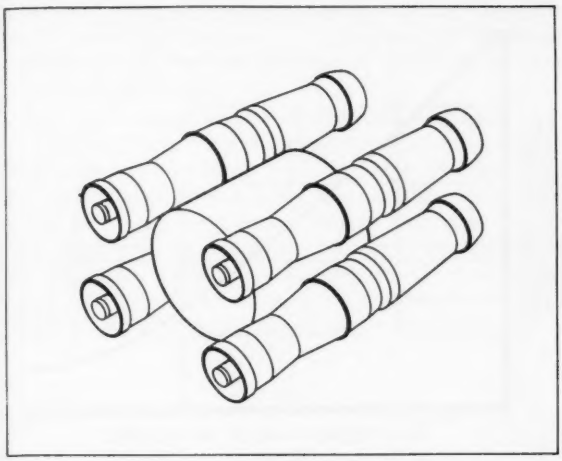

Figure 1. Typical power plant.

high temperatures. When improved materials are available, we would expect the nuclear power plant to advance rapidly in its overall efficiency, with a consequent improvement in ability to install such power plants in airplanes of smaller size than those currently contemplated.

BASIC POWER-PLANT CHARACTERISTICS ARE THREEFOLD

In order to clarify and categorize the air-frame reactions to the presence of the nuclear power package, let us first determine just what the basic characteristics of the power plant are which dictate their recognition in the air-frame design. In their most elementary form, they are only three:

(1) A highly concentrated weight in the reactor.
(2) A powerful radiation field emanating from the reactor.
(3) No consequential flight endurance limitations by the power-plant fuel.

We believe that the first of these characteristics is quite familiar. The reactor with the shielding attached to it, generally called the "reactor-shield assembly," is a very dense affair. It may weigh from 25,000 to 100,000 lbs., but, instead of having a density of 20 to 25 lbs. per cu.ft. (as have modern turbojets) or 50 lbs. per cu.ft. (as has typical chemical fuel), the reactor-shield assembly may have a density of from 100 to 200 lbs. per cu.ft. We will explore the implications of this concentration of mass later.

The radiation field from the reactor proper is also well known. If it were possible to put as much shielding on the reactor as is done on ground reactors, we could reduce the radiation therefrom to a negligible amount. But the total weight of shielding required to do this would be prohibitive; in fact, we are forced to the so-called "divided shield" concept in order to reduce the total shield weight to an acceptable amount. Divided shielding (Figure 2) is, of course, simply a division of the shielding between

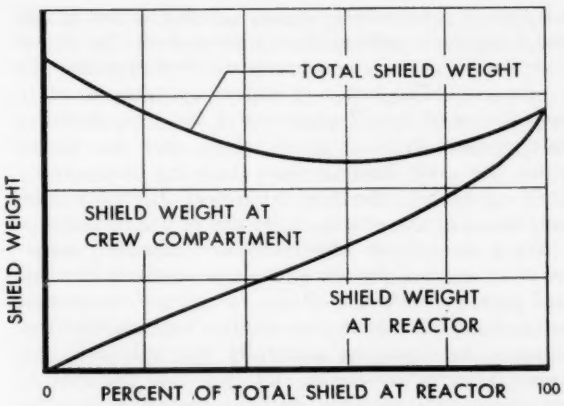

Figure 2. Shield dividedness effect on total shield weight.

the reactor and the crew compartment in such a fashion as to result in near-minimum total shielding weight. As is apparent from the illustration it is possible to go too far in either direction and, as we will discuss later, the optimum dividedness is not a function of total shield weight alone but must also be compromised in recognition of several other factors. Divided shielding, then, while permitting lower radiation levels in the crew compartment for a given total shield weight, actually results in *higher* radiation levels every place else in and around the air frame.

The third power-plant characteristic is the most familiar and is the fundamental reason that we are in this business at all. Its significance in a major sense is quite obvious; in many minor senses, however, it leads to less familiar, but interesting, effects which we will discuss.

Now we have established the assumptions under which we will operate in our discussion, and we have classified the important power-plant characteristics which will bear, singly and together, on our airplane design. We propose first to examine the disadvantages of having the nuclear propulsion system in the airplane, and second, to investigate the benefits to be expected.

Probably the first difficulty encountered by the designer in his first layout of a nuclear-powered air plane is the tremendous congestion at the center of gravity of the airplane. It appears to be generally desirable to have the engines in close proximity to the reactor to reduce the many problems of transferring the reactor heat output to the engine air. The combination of the reactor shield assembly and the turbojets accounts for something in excess of 50 per cent of the airplane equipped weight empty. The wing if unswept, certainly passes through the fuselage in the c.g. area. The center of gravity of the fuselage structure inherently lies close to the airplane c.g. The main landing gear must lie very close to the airplane c.g. Aircraft fixed equipment tends to be spread out in the fuselage and cannot be very

helpful in rebalancing. About all that is left to aid the designer in pulling the c.g. away from the power plant are the crew compartment shielding and the empennage. The latter of course operates so as to cancel part of the effectiveness of the crew shield in this respect. It is apparent, then, that the power plant, the main landing gear, the wing, and—to reduce c.g. travel—the disposable load all vie for fuselage space at the center of gravity of the airplane.

Wing sweep can alleviate the congestion somewhat by moving the wing-fuselage juncture forward and perhaps providing thick enough airfoil sections to stow the main gear. Our studies indicate that this compromise does not generally pay off, and that sound, imaginative design can overcome the important congestion problem without resorting to wing sweep.

CREW COMPARTMENT DESIGN DIFFICULT AND VITAL

The second problem we should like to discuss is that of crew compartment design. Layout of comfortable, efficient crew stations is a real art requiring expert attention, even in conventional airplanes. The divided shield concept focuses so much more attention on this arrangement, however, that our former efforts seem almost trivial by comparison. The crux of the whole situation is, of course, the thickness of shielding material distributed on all sides of the crew compartment. Simple geometrical considerations show that every cubic foot of shielded volume costs from 50 to 500 lbs. of shielding. This situation makes it mandatory that every possible effort be made to save every bit of volume not essential. Human engineering to a degree never before necessary is demanded, and equipment refinement and miniaturization of all items which must remain with the crew is of paramount importance. When crew station volumes, including equipment, get down into the range of 50 to 75 cu.ft. per man, apparently simple problems of movement within the compartment and of space to stretch the body to full length are no longer easy. In addition, provision of safe and rapid emergency crew escape is more difficult because of the thick shielding, as well as the restricted space. It is of vital importance that design in this area be done in acute consciousness of the relative value of the pound saved to the unit of human efficiency sacrificed.

One other aspect of crew station design should be pointed out. Nuclear radiation, whether neutrons or gamma rays, is basically directional in nature—that is, if the nuclear airplane were in a vacuum, only a rear face shield would be required at the crew compartment. But, as shown in Figure 3, the radiation is scattered, or deflected, through angles as high as 180 deg. by hitting atoms in the air, or aircraft structure, so that considerable radiation enters the crew compartment from the sides and from the front. Because the radiation energy decreases as the scattering angle increases, the side radiation is weaker than the direct beam on the rear face, and

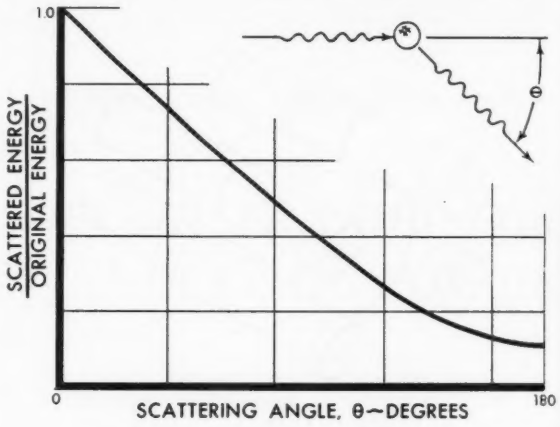

Figure 3. Radiation scattering.

that hitting the front face of the compartment is weakest of all. Now (Figure 4) the lower the energy of a given radiation flux, the less the material thickness required to attenuate it by a given factor. In addition, scattered radiation has to travel a greater distance, from a simple geometrical viewpoint, which leads to a flux decrease inversely proportional to the square of the distance traveled. This situation leads to two interesting conclusions. The crew compartment shielding becomes progressively thinner as one progresses from rear to sides to front, which means that not just cubic feet but the geometrical disposition of the cubic feet is important in optimizing crew station design. Also it is much easier to replace the relatively thin front shielding with transparent materials of equivalent radiation attenuating power than it is to make such a replacement on the sides; the rear face is worse than either sides or front. Thus windows in the crew compartment will likely be nonexistent in the rear face, limited in the sides,

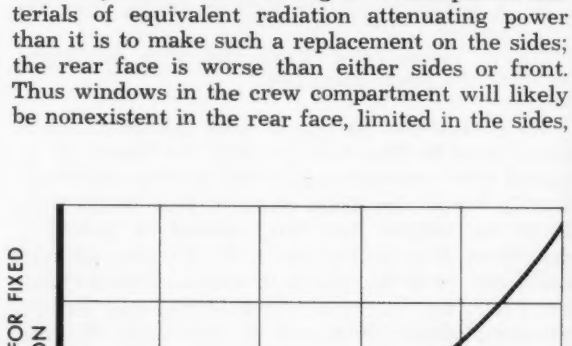

Figure 4. Shield change with flux energy.

and only difficult in the front because of the still-consequential thickness of transparent material necessary to replace the more efficient opaque shielding removed.

The directional nature of the radiation leads also to the fact that aircraft structure and components are useful as shielding material, and judicious use of such things as the wing box, landing gear, pay load, and fuel for landing go-arounds can reduce the thickness of shielding required on the crew compartment rear face (Figure 5). Care must be taken, of course, to account for the expenditure of disposable items in this approach to shield savings.

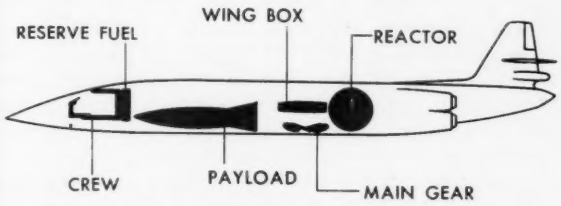

Figure 5. Equipment and structure as shielding.

STRUCTURAL RELIEF NOT AVAILABLE

The divided shield concept leads directly to another design situation which is not ideal. We normally think of the fuel and equipment weights carried in a fuselage (Figure 6) as being rather well distributed along its length. This permits relatively efficient and light fuselage structure and results in reasonable moments of inertia in pitch and yaw and in fairly high frequency fuselage vibration modes. Installation of a heavily shielded crew compartment near the nose of the airplane changes this situation profoundly. A heavier fuselage structure is required for simple static loads, at least. It may be that the dynamic loads arising from the much lower natural frequency in vertical or side bending will lead to further structural increases. The effect of increased moments of inertia in pitch and yaw on the several

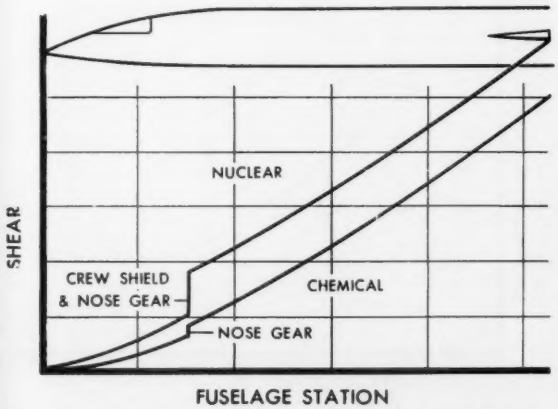

Figure 6. Comparison of fuselage flight shear loads.

dynamic stabilities of the airplane will probably not be great (we have not explored this in detail) but they must be considered.

In conventional aircraft, considerable primary wing structural weight is saved by so-called "inertia relief"—that is, any weight items which are installed outboard of the wing root decrease the wing structure necessary to carry a given total airplane gross weight. Virtually all airplanes enjoy some of this saving because of fuel carried in the wing; many have the further advantage of tip or pylon-mounted fuel tanks; wing-mounted power plants, either partially submerged or in strut-mounted nacelles, afford considerable relief; landing gear hung from the wing provides some help; and internal or external wing-mounted armament affords savings. The inertia relief of all of these items is somewhat tempered, of course, by the additional down-bending inertia loads they cause in landing or taxi conditions.

The all-nuclear airplane will probably benefit from few, if any, of these bending reliefs (Figure 7). The lack of any consequential amount of chemical fuel certainly eliminates aid in that respect. The overriding desirability of having the engines close to the reactor to reduce the heat-transfer problem will most likely keep the engines in the fuselage. If thin, straight wings are used, gear stowage therein

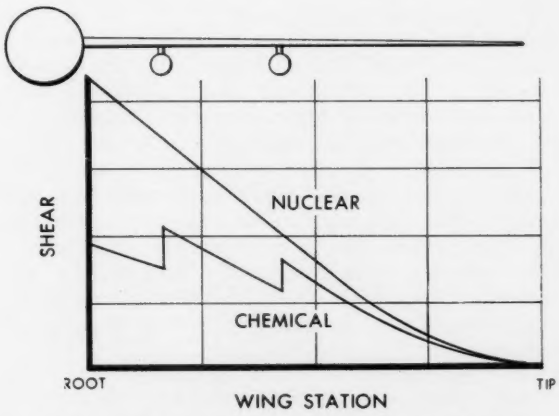

Figure 7. Comparison of wing flight shear loads.

is not too attractive. The only bending relief item remaining is armament; some aid may obtain in this direction.

Another type (Figure 8) of structural relief generally exploited in conventional aircraft is that due to the difference in the maximum gross weight and the landing weight, due mainly to fuel consumed during the mission or, if necessary, dumped prior to landing. Typically the landing gear, after satisfying take-off and taxi load requirements,need be designed for something like half of the maximum gross weight at landing impact. Since the nuclear airplane we are considering uses essentially no fuel during its

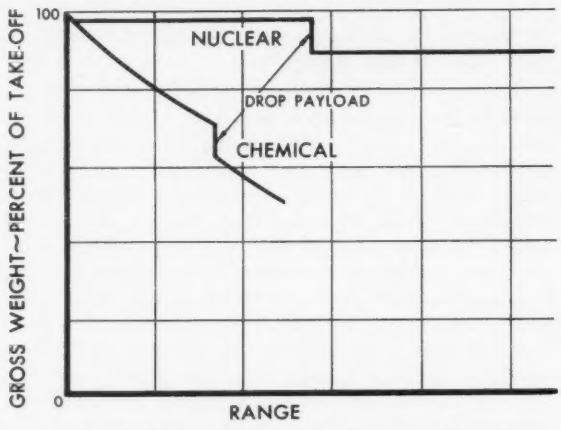

Figure 8. Gross weight variation with range.

mission and cannot even be counted on to have disposed of its pay load, no such relief is in sight; the landing gear will have to be designed for the full airplane gross weight.

The last type of weight relief normally exploited in conventional aircraft is the flight performance increase as the gross weight decreases because of fuel consumed during flight. The landing performance is improved by the same gross weight reduction which permitted savings in the landing-gear design. Similarly, maximum speed, cruise speed, rate of climb, and maneuverability all get better during a flight as fuel is consumed. The all-nuclear airplane does not benefit in this fashion and, though the calculation and presentation of nuclear aircraft performance is much simplified, the simplification is at the expense of performance gains at lower gross weights.

Though several of the points discussed so far are outgrowths, to a varying degree, of the radiation from the reactor, let us now consider the effects of this radiation more directly. We shall examine four major problem areas in which the radiation field is the prime factor in reaching certain development decisions:

(1) Crew personnel radiation exposure.
(2) Maintenance personnel radiation exposure.
(3) Air-frame materials damage.
(4) Air-borne equipment integrity of operation.

We believe that we may state without reservation that the flight crew is the single most sensitive element in the air frame from a radiation point of view. Unfortunately the determination of the tolerable human radiation dose is very difficult and may well prove to be one of the most complex research areas in the attainment of operational aircraft. Gamma rays and neutrons of the same intensity damage the body to different degrees, to begin with, and the effects of each of these two types of radiation also vary with the energy of the radiation. As a further complication, various organs of the body are sensitive in varying degrees to radiation, and the effects on these organs become maximum at various times after exposure. Finally, all of the biological reactions are to some degree functions of the dosage rate, the total dose, and the time between exposures. The difficulties faced by the radiobiological people in endeavoring to set up exposure criteria for crew personnel are evident.

Once such criteria are established, however, the shielding engineer and the air-frame designer are just beginning their analysis in order to translate the biological specifications into an operational airplane shield. The combined shielding at the reactor and at the crew station must provide an optimal ratio of neutron to gamma flux inside the crew compartment. Decisions are necessary by the eventual user of the airplane regarding the total number of flight hours desired for an individual crewman, defining the expected time between flights, and stipulating the number of hours per flight. Recognition in all of these respects must be given to the different operational characteristics of the airplane in peacetime training and proficiency flying and in wartime campaign flight. It should be noted here that the separation distance between the reactor and the crew is an important factor in shield design and that it, too, is a variable susceptible to limited control by the designer in the original layout of his airplane. The shielding savings due to increased separation distance must be weighed against the increased fuselage weight and generally unfavorable aerodynamic changes concomitant.

The foregoing discussion of *crew* personnel and radiation leads naturally to that of *ground* personnel and radiation. It is in this regard, we believe, that the largest single penalty of the divided shield concept becomes apparent. It is obvious (Figure 9) that, if a dosage rate has been established for the flight crew and if a consequential fraction of the total shielding is at the crew station, then the dosage rate everywhere *outside* of the crew compartment is much higher than it would be if *all* of the shielding

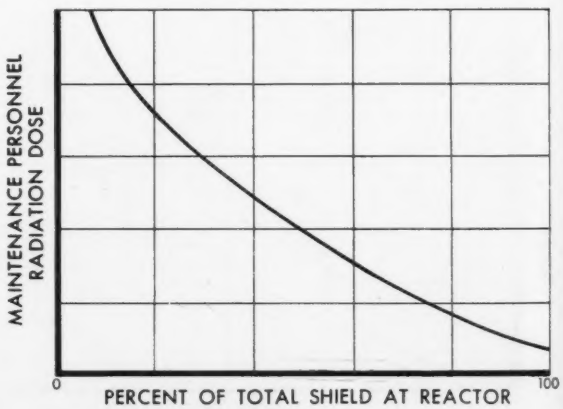

Figure 9. Shield dividedness effect on ground crew radiation dose.

were at the reactor. In other words, any aspect of shield design which takes advantage of the fact that the flight crew is in a restricted, delineated area tends to increase the radiation flux everyplace else.

There are two more aspects of the service and maintenance problem which we will mention before turning to the favorable factors. Because a large percentage of aircraft service and maintenance work is on the power plant, this work will have to be done in an area closer to the reactor than the crew compartment. Also, it will probably not be practical to limit the work of maintenance personnel in accord with a high permissible dosage rate at widely spaced time intervals; they should be able to work at least a half day, 5 days a week, on nuclear airplanes. This means that they will probably be limited to a much smaller dosage rate than will be flight crew, very probably near the present Atomic Energy Commission maximum laboratory dosage rate of 7.5 milliroentgens per hour. Crew dosage rates may be 10 to 100 times this value.

"DARK" MAINTENANCE SITUATION LIGHTED BY IMPROVEMENT FACTORS

The maintenance situation looks very dark, indeed, at this point. Let us examine the factors which improve it.

First, the reactor will not be at full power during service. It will probably be completely shut down. Unfortunately a good deal of decaying radioactivity remains even in this state, but the decrease compared to full power is greater than one order of magnitude.

Second, it is probably not desirable or necessary to initiate service immediately after shutdown; since the radioactivity remaining is decaying with time, a wait of a few hours decreases the dosage rate. Along these same general lines, the flux after shutdown is almost exclusively gamma rays, which simplifies the problem somewhat.

A third aid in the maintenance picture is the possibility of removing from the reactor some of the radioactive materials after shutdown. The degree to which this may be accomplished is unalterably defined by the structure and design of the specific reactor, but some cases hold considerable promise of flux reductions by one or two orders of magnitude.

The last recognized means of achieving normal, manual power-plant service is through the use of a technique known as "shield augmentation." Since neutron emission is not a postshutdown problem and since the reactor neutron shield might conceivably be a liquid, it is possible to consider draining or removing the neutron shield and replacing it with a high density liquid or slurry having much better gamma attenuation characteristics. Flux reduction by better than an order of magnitude is certainly possible if the mechanical difficulties can be overcome.

We have so far carefully avoided mentioning the use of remotely controlled handling devices for service and maintenance. We believe that some simple operations can be performed by manipulators of one kind or another—for example, accomplishment of several of the flux reduction means we have discussed would require such an approach. But for plain, everyday, operationally practical upkeep of air frames, power plants, and equipment, it is next to impossible to replace the two hands and the Mark I eyeball of a mechanic with steel claws and a TV tube. We have endeavored to qualify this statement, and it appears that something between 5 and 10 times the number of manhours is required to accomplish typical service work by manipulators *with direct vision* as is required with a conventional manual contact approach. Let us qualify these remarks to a limited extent; there will certainly be a number of areas where adjustments and checks must be made either before or after shutdown and ground-safing. It will be of paramount importance for the air-frame designer to provide for these procedures in such a fashion that manipulators can be used as efficiently as possible. In the event that the reactor can in no way be rendered ground-safe, it will be necessary to remove the power plant *in toto* to special maintenance shops for its service, at the same time making the rest of the airplane accessible to normal service operations. In this case the design of the power plant for manipulator maintenance, even in special shop areas, will be a supreme test of the power-plant designer's skill.

We have discussed the biological damage of nuclear radiation and its impact on many aspects of aircraft design. A simpler, more easily tested, and probably not quite so profoundly damaging characteristic of radiation is in the materials of which airplanes are made. A really thorough assessment of the problem is beyond the scope of this paper; many of the basic mechanisms of radiation damage are not yet fully understood by even the metallurgists and physicists. In addition, material damage *outside* of the reactor is serious, in general, to the degree to which the divided shield concept is exploited. Thus the trend toward more shielding at the reactor, suggested by service and maintenance considerations, aids radiation damage reduction similarly.

MATERIAL RADIATION DAMAGE MAY PROVE SIGNIFICANT

The fields in which radiation damage may prove significant are at least eight. They are not listed in any particular order because their relative occurrence, and the degree to which the individual effects are important, vary with the flux level and type, the material being considered, and the use intended for the material in the airplane. As we will see, only a few of these should prove important and only a couple will be vital.

The first field, *dimensional changes,* refers to changes occurring without regard to stress on the

subject part. The total integrated dosage required to cause significant change is such that only materials inside the reactor shield itself could conceivably be affected. It is thus very improbable that the air-frame designer need consider this.

The second item, *creep acceleration,* is, in the purest sense, of interest primarily as a dimensional change. As in the first item we mentioned, creep acceleration will be most critical inside the reactor, but it may also prove to be somewhat troublesome in some instances in the air frame. It appears that some materials undergo considerable creep acceleration at high stress levels and/or high temperatures due to radiation. Certainly in supersonic aircraft with significant aerodynamic heating of structures and even in subsonic airplanes having prestressed connectors, it will be necessary for the designer to account carefully for potential radiation-accelerated creep characteristics.

Our third category, *hardness, strength, embrittlement increases,* may prove quite important. Fortunately, work-hardenable alloys in the hard condition are not further hardened appreciably. Nevertheless, for fittings and connectors near the reactor, the possibilities of increases in stress concentration and notch sensitivity and decrease in impact strength will require consideration, as will the effects on fatigue life.

Our fourth and fifth terms, *accelerated diffusion at faying surfaces* and *accelerated stress corrosion,* spring from a single characteristic of radiation—it accelerates diffusion of atoms in a metal. Plated pistons and riveted or bolted connections where dissimilar metals rub may, through microdiffusion across the plane of contact, lead to embrittlement or other important metallurgical changes. Accelerated stress corrosion is probably much more serious a problem in the reactor, but reactor attachment fittings and support structure may require some consideration in this respect.

The sixth item, *transmutation,* is included mainly for completeness. It is certainly true that, under slow neutron irradiation, most metals gradually transmute into others. For example, aluminum becomes silicon, and copper becomes nickel and zinc. Some of the metals become isotopes of the original element, but none of the common structural materials is transmuted into liquids or gases and, even more important, the percentage of the original metal converted in an airplane lifetime is probably less than the percentage of unknown impurities in the original material. Thus transmutation is not expected to be recognized in the air-frame design.

Induced radioactivity, the seventh category, appears to be one of the most important in the entire list. In general, the material being bombarded by neutrons must have four characteristics for it to be critical in this regard.

(1) It must exhibit a fairly high tendency to capture neutrons within its nucleus.

(2) The isotope resulting from this capture must be unstable—that is, radioactive.

(3) The radiation emitted from the isotope must include a consequential amount of medium- or high-energy gamma rays.

(4) The half-life of the isotope must be significantly long.

Speaking loosely, it is the product of these factors which is important; a material deficient in one respect may be so high in another that it remains on the critical list. Fortunately such materials as aluminum, iron, titanium, and magnesium are markedly deficient in at least one of the criteria. Cobalt, zinc, tungsten, manganese, chromium, and molybdenum, on the other hand, are somewhat discouraging, to various degrees. In general it appears that it is not the fundamental element of common materials but their alloying constituents which are most troublesome. No matter how the lists of good, intermediate, and bad materials finally end up in detail, it is obvious that accurate material quality control, not only of alloying elements but also of impurities, will be of sharply increased significance. The designer will have to become fairly conversant with induced radioactivity characteristics and will have to keep his material specifications within the bounds prescribed to keep the air frame from becoming too hot to handle.

We have saved *molecular structure changes* until last because they are characteristic of mainly organic materials, and organics, in turn, respond to irradiation in mainly this fashion. Peculiarly enough, either of two opposite effects predominates in organics in this regard. In most cases the basic molecular chains are broken, resulting usually in poorer physical characteristics, often in gas evolution, and eventually in destruction of the material as a usable component. In a few cases the opposite occurs: the basic molecular chains crosslink themselves without cleaving, and the result is greater strength and density and generally improved physical characteristics, particularly heat stability. Most of our typical aircraft organics—such as rubber, lubricating oils, fuels, hydraulic fluids, electric insulations and dielectrics, and the transparent butyrates and polyesters—are hurt to one degree or another by radiation. Rubbers lose elasticity; lubricants, fuels, and hydraulic fluids evolve gas and tend to gum; and the transparent plastics weaken and discolor. Fortunately, the majority of these materials will probably last through one or more overhaul periods. In the particular case of organic fluids, some latitude of choice is possible in selecting materials inherently better than others, and the use of additives can be helpful in promoting radiation stability. But again, as with metals and alloys, a whole new additional criterion of material selection must be learned and applied if sound aircraft design is to accrue.

ELECTRONIC EQUIPMENT MAY SUFFER SERIOUS EFFECTS

We have hinted at changes in dielectric properties of materials previously. If we view electronic equipment operating in a radiation field, we find that even more serious effects may be expected. Perhaps the most serious is the possibility that the ionized sphere of air surrounding the airplane and centered at the reactor may attenuate electromagnetic propagation. If this proves to be true, then radio transmission and reception in the airplane would be adversely affected, and, even more critical, radar ranges would be reduced. These phenomena would occur, of course, only to the degree that the flux level outside the reactor is high, and tendencies toward greater reactor shielding would reduce this type of deterioration of equipment performance. It is still not known whether or not this attenuation occurs at all frequencies, however, or, if it does, what the threshold ionization level for detectable attenuation is at the various frequencies.

The effect of the radiation on electronic components is better known today. Four known types which become essentially unusable in high radiation fluxes are germanium transistors, electrolytic condensers, phototubes, and bias cells. These are all replaceable by other types which appear to be quite satisfactory even under long, fairly intense irradiation. But induced radioactivity again assumes considerable importance in that, for example, capacitors, relav and switch contacts, and vacuum tubes become radioactive fairly readily, and a cooling off period of several weeks before handling such components would create a pretty difficult service problem in the aircraft electronic systems. Considerable relief in all these respects is potentially available to the aircraft designer through placement of the electronics gear far from the reactor and by locating it in the radiation shadow of some mass in the airplane. Some of the reactor and engine controls, however, will undoubtedly incorporate electronic elements of necessity close to the reactor, and these will not be so easily rendered satisfactory.

Three other equipment problems should be mentioned here. Relay and switch contacts wear faster in the ionized air of a radiation field, and photographic film fogs very quickly in even modest fluxes. Ozone, a product of air ionization, hastens the deterioration of rubber.

Viewing the equipment problem in general, it is seen that a majority of the work to be done in improving components is outside of the control of the air-frame designer, but he can, by efficient arrangement of his layouts, ease the radiation level to which much of the equipment is subjected by as much as two to four orders of magnitude; his potential contribution in this respect should certainly be recognized early in the equipment development program.

We mentioned earlier the likelihood that the nuclear engines would be kept close to the reactor and, therefore, that wing-mounted engines would probably not be available for wing bending relief. For the sake of completeness, the other implications of not hanging the engines on the wing should be mentioned. By scrutinizing the reputed and real advantages of wing-mounted engines, we can quickly see what design problems may accrue if wing mounting is not feasible. The oldest reasons for wing engines are the requirements of propeller clearance and some reduction in fuselage vibration. Neither of these is particularly applicable to a nuclear-powered turbojet airplane, though the clearance problem would be if nuclear turboprops are considered. The attainment of good turbojet inlet ram recovery is always simpler with nacelle inlets, and the difficulties of jet exhaust washing the aft fuselage are automatically eliminated. Both of these problems can be solved with fuselage installations, but more design attention is required.

Main landing-gear stowage often works out very nicely in engine nacelles but can be handled in the fuselage or wing root. The absence of cutouts in the wing for gear stowage is of consequential advantage in attaining high torsional stiffness. Maintenance accessibility of wing nacelles is *inherently* better than that of engines submerged in a fuselage, but the differences can be made slight by good design. Engine fires in the air or explosive failure of a turbojet are *intrinsically* somewhat better isolated in individual nacelles, but there are many sound design approaches to equal or better the situation with submerged power plants. The newest advantage of wing engines is the use of the engine mass to aid in increasing critical wing flutter speeds. This is mostly applicable to swept wings of high aspect ratio and is thus not necessarily appropriate to most of the configurations likely in the nuclear bomber.

Some of the problems created by locating the engines in the fuselage are real, some are academic. In general, we are confident that the advantages of such an installation far outweigh the advantages of wing mounting, particularly in the case of the nuclear airplane.

CHALLENGE TO DESIGNERS SEEN IN NEED FOR COOLING APPARATUS

In the design of today's turbojet aircraft we have gotten far away from the cooling radiator problems of the old liquid-cooled reciprocating engine. It appears that, with nuclear power, we will have to brush up on this skill. Some of the potential nuclear cycle candidates have radiators in the turbojets, but these are outside of the direct responsibility of the air-frame designer. We refer, instead, to the fact that at least the shield, and possibly some of the other reactor components, may require cooling through the use of a relatively conventional liquid-to-air heat exchanger. The amount of heat to be handled may approach 10 per cent of the total reactor power. Incorporation of a cooling system of this capacity in a high-speed airplane with only

nominal weight cost and reasonable drag penalties is a great challenge to the designer and thermodynamicist and requires extreme integration of the air-frame and power-plant design effort.

Another cooling problem is inherent in reactors of all varieties. When a reactor is shut down, though the fission process stops, considerable heat continues to be generated by the decay of the fission products. This phenomenon, known as "afterheat," decays with time, but the amount of heat during the first week or two is great enough to require forced cooling to avoid having the core melt itself and destroy the reactor. The situation leads to one easy and one difficult problem. Following a normal landing, either an engine must be run continuously to remove the afterheat, an auxiliary air supply must be attached, or the reactor fuel must be removed. In the event of a crash or an accident during take-off or landing which stops all engines, the afterheat is certainly going to damage the core.

The last design problem created by the nuclear power plant is one of the potential, not certain, type. It is possible that the response characteristics of the reactor to increased or decreased power demand, either inherently or because of limitations built in for safety, will be slow compared to those desired during take-off or landing. Solution to such a difficulty intimately involves both the power-plant and the air-frame manufacturer and should be thoroughly analyzed by them quite early in the development of the power plant and air frame.

We have now completed a discussion of the design problems expected to result inherently from the application of nuclear power plants to useful aircraft. We are sure that many of those apparent difficulties looming as most serious now will prove to be most tractable to handle; we are equally sure that some of the most innocent will prove to be real backbreakers. In any event, let us proceed to a survey of the air-frame design *advantages* which we may reasonably expect to accrue with our nuclear power plant. Because discussion of *new* problems is inherently more interesting and stimulating than discussion of *ex*-problems, we will treat the advantages very briefly.

We shall only mention the salient advantage of increased endurance, or range, since it has been so frequently extolled in every discussion of nuclear-powered aircraft. We will see a little later, however, that this lack of endurance sensitivity implies some very definite secondary attributes to be enjoyed in actual airplane design and construction.

One of the immediate enjoyable prospects following removal of chemical fuel from an airplane is the reduced center-of-gravity travel to be expected (Figure 10). Though some c.g. movement will remain, associated with the armament, pay load, gear position, and crew, the net result should be a reduction of travel from the typical 12 or 16 per cent to half that or less. This has one significant effect—the

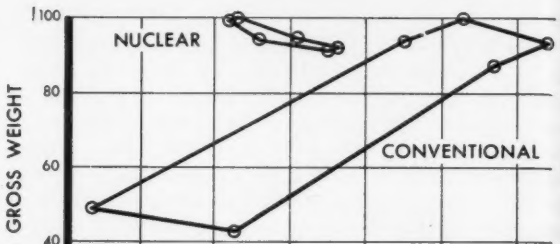

Figure 10. Comparison of balance diagrams.

tail volume may be reduced consequentially. This is brought about, of course, because all of the critical longitudinal trim moment changes are reduced, and the overall tail moment envelope required becomes accordingly smaller.

Another very real advantage having to do with center of gravity and trim problems arises from the divided shielding concept. Even if the most-rearward c.g. limit is held closely during design, it usually tends to drift aft as soon as the airplane gets into service and modifications commence; often the compromises necessary to handle the problem are very undesirable. In the nuclear aircraft a new means of compensating for this is available. If the shield dividedness is such that small changes in dividedness cause very small changes in total shielding weight, as is expected to be the case, then it will be possible to increase slightly the shield on the rear crew compartment face and decrease the reactor shadow shield thickness. This is a powerful tool for changing balance, particularly in the terminal phase of project design, and is almost free weightwise. We might add that, if the accuracy of the science of shielding computation does not improve considerably before we design the first airplane, we are going to be in real unknown weight and balance troubles in even the design stage!

You will recall that we discussed the lack of wing inertia relief at some length when we considered the disadvantages imposed by the nuclear power plant. The removal of the inertia relief items from the wing provides, however, modest compensation. In essence, the wing structure becomes much simpler, cleaner, and more efficient because the compromises in structural arrangement and design for fuel stowage and engine mounting need not be made. Whereas it has been in the past fairly easy to provide access doors in the multirib structural box of thick, low-speed wings, it cannot be done cheaply, weightwise, in thin multispar, high-speed

wings. Thus a consequential weight-saving accrues because the nuclear airplane does not need the internal wing access.

We mentioned earlier that if wing sweep is not used, the area around the airplane center of gravity will likely be somewhat congested by the necessity of locating the wing box, landing gear, and nuclear power plant close to the c.g. Again the congestion problem is not all bad in that the major load paths from the gear to the power plant and from the wing to the power plant will be very short. This leads to greater structural efficiency and reduces the weight of heavy structure required to carry the power-plant load to the wing and main landing gear.

COST OF AN EXTRA POUND NOT SO GREAT

If one views the conventional chemical airplane as being built up of completely linear components —that is, if engines, air-frame equipment, and air-frames are all rubber so that they can grow or shrink to match perfectly any change in gross weight and size to maintain airplane *performance* constant—then the addition or subtraction of a pound of weight causes a substantially greater change in the total aircraft gross weight. Since such component flexibility is not generally available *in fact* except in the air frame itself—wing area, for example—the cost of added weight normally results mainly in a penalty in some phases of aircraft performance. But the best real measure of the penalty is still obtained by assessing the gross weight increase on a "rubber" airplane. In chemically powered aircraft the gross weight cost for a pound of added weight may be anything from 3 to 10 lbs. This is obviously a seriously large ratio, and a major portion of it is generated by the extra fuel and associated system provisions necessary to keep speed, rate-of-climb, and range characteristics constant.

The all-nuclear-powered aircraft enjoys a marked advantage in this respect. Though its engines and reactor, its landing gear and equipment, and its air-frame structure must go up somewhat in weight, as do the same elements of the chemical airplane, the net increase is considerably less, particularly when the mission incorporates a sizable endurance requirement. It appears that the weight-increase ratio may vary between 1.5 and 4, rather than 3 to 10.

If the situation is cast in terms of real, rather than rubber, airplanes, a similar advantage accrues. The chemical version will suffer a modest decrease in speed and climb performance and a more serious decrease in range. The nuclear airplane will lose speed and climb performance only. This entire re-assessment of the cost of a pound will no doubt have a marked effect on the criteria applied to deciding the wisdom of equipment addition to nuclear aircraft.

We should mention, before leaving this particular subject completely, that the real cost of a pound of additional drag is susceptible to the same analysis and gives the same results. This is of particular importance:

(1) When equipment protruding into the airstream is added, or when the aerodynamic airplane is modified for new equipment or,
(2) If the original estimates of airplane drag prove to be lower than the drag actually encountered.

By far the predominant factor in the vulnerability of chemically powered aircraft to nonexplosive bullets, to shrapnel and debris, and to small explosive shells is the fuel system. It achieves this dubious eminence because not only is a square foot of fuel more sensitive to projectiles than all other aircraft elements excepting personnel but also there are many times more square feet of fuel than of any other component or system. In addition the fuel system has the further unfortunate characteristic of spreading damage by fire quickly and extensively; it thus generates by its inherent qualities a continuing, multiplying source of damage to other systems in the airplane.

The all-nuclear airplane has an obvious and tremendous superiority in this respect. The reactor itself may prove to be somewhat vulnerable, but its vulnerable area is relatively small and the net gain from elimination of large fuel capacity will be enormous. It should be noted here that engine fire hazards in non-combat operation of conventional aircraft are great because of the fuel-loaded plumbing, pumps, and controls adjacent to the engine. If chemical fuel is used only for take-off and landing in the nuclear airplane, the entire system near the engines can be purged and rendered inert during nearly all of the mission.

In addition to the reduction of fuel system and power-plant vulnerability is that associated with the crew. The rather thick layers of shielding surrounding the crew compartment will likely protect the personnel almost completely from fragments and small projectiles, particularly those approaching from the sides, top and bottom, and aft.

For the sake of fairness we should mention that the nuclear airplane does not have any particular advantage against *large* explosive warheads. These are designed to cripple air-frame structure *wherever* they hit, and no outstanding differences may be expected between chemical and nuclear airplanes, with the possible exception of the crew station area where the shielding may be of some help.

ENDURANCE ADVANTAGE OUTWEIGHS ALL NEW PROBLEMS

Viewing the comments we have made, both good and bad, now in retrospect, it would appear that the aircraft deigner is to be faced with many more new problems than he is to be relieved of old ones. This is most assuredly the case if we count only the *numbers* of problems on each side. If we consider *both* quantity and quality of the advantages and disadvantages, ignoring the flight endurance advantage,

we will again come out on the short end as designers. But the importance—the quality—of the endurance characteristic is such as to dominate completely this apparent negative balance and render it unimportant. And this unique characteristic is one to be greeted enthusiastically, not by the designer alone, but also by the military analyst, the military operating command, and the aircraft crew. Clever, creative aircraft design will remain the *sine qua non*, as it has been in the past, if we are to exploit the nuclear power-plant application to the fullest.

A test facility, designed for elevated temperature environmental study of aircraft and missiles, has been developed by the Westinghouse Electric Corporation. At supersonic speeds of such vehicles, it is expected that materials may be subjected to temperature levels of 2500° F or more. The facility enables study of associated structural design problems. Its equipment includes banks of quartz infrared lamps as a heating source, each lamp being rated at 1000 watts at 240 volts. With these lamps, a temperature of 2500° F can be attained in 12 seconds. The lamps are controlled rapidly through a broad heat range by ignitron tubes. Such control characteristics permit investigation of transient as well as steady-state problems.

—from "Westinghouse Engineer," November 1957

In a recent technical paper presented before the Society of Automotive Engineers, R. W. Middlewood and R. B. Ormsby, Jr. have supported the practicability of building a large nuclear-powered air transport with a virtually unlimited range. The feasibility of carrying a 50 ton payload for a non-stop distance of about 24,000 miles was discussed. Such an airplane would be comparable in size to the current C-130 combat transport. The chief design problem noted was that of shielding weight.

—from "Electrical Engineering," December 1957

CAPTAIN V. E. DAY, USCG

THE COMPTROLLER'S ROLE IN AN INDUSTRIAL FUNDED MILITARY INSTALLATION

THE AUTHOR

entered the Coast Guard from the State of Idaho and was graduated with honors from the U. S. Coast Guard Academy, class of 1927. He has served in various capacities aboard major types of Coast Guard vessels; as instructor, engineering subjects at the Academy, as Planning Officer, Coast Guard Yard; and as Chief, Engineering Divisions at New York and Seattle. He has commanded the Cutters Tampa (renamed Saranac) and the Ingham. His primary interests and the majority of his assignments have been in engineering. He has been most active in promoting safety within and without the service and is the author of several papers on this subject. He is a member of the Society of Naval Architects and Marine Engineers, the Society of American Military Engineers, this Society, and Tau Beta Pi, New York Epsilon.

He now occupies the two-hat position of Industrial Manager and Commanding Officer of the U. S. Coast Guard Yard at Curtis Bay, Maryland. This, the only Coast Guard yard, is patterned in most respects like a naval shipyard and constructs most of the Coast Guard's boats, small vessels, and buoys, repairs all types of vessels and does repairs and development work for other government agencies as required.

WHEN THE WEATHER turns for the worse, it is customary for Coast Guard patrol craft to put to sea, to be available on-the-job, if needed. "Semper Paratus" is our official motto, but "You have to go out" unofficially backs it up. It has been traditionally observed through many harrowing experiences.

A winter storm off the Washington coast made the Pacific anything but pacific. In anticipation, two of our 36-ft. motor lifeboats had sallied forth, and well it was, for a fishing vessel broke down almost on the edge of the breakers. The nearest boat took the fisherman in tow and headed out, but a cross sea parted the tow line and it became fouled in the lifeboat's propeller. A quick radio appeal soon brought the other lifeboat, who took over the tow of both. But the disabled lifeboat broke loose. The weather was so bad it seemed impossible to re-establish the tow, and so the first boat was left to shift for itself while the second successfully took the fisherman several miles down the coast to safety through the inlet. All this took place in the dead of night. The disabled lifeboat drifted into the breakers and after two harrowing hours was cast high on the beach, having rolled over five times. The men aboard were trained for such an emergency. Inside with the hatches secured behind them, they were bruised a bit, as you can imagine, for outguessing the boat's motion, with no eye level reference, was impossible. But the fact is, they came through the experience alive, and so did the boat. The storm waves cast it so far up the beach, we had to hire a contractor to bring equipment down and dredge a channel and relaunch the boat into it. I inspected that boat after it returned to its base under its own power, and I could find no evidence of any significant damage. It was only messed up by things inside which proved a bit too portable for sidewise and upside down navigation.

The reason I have chosen this story, among hundreds available, is that this wonderful boat, which proved it could take the worst possible punishment, was built at the industrially funded U. S. Coast Guard Yard.

I am not going to go very deeply into a discussion of our business methods, but that we may have a

common understanding of the financial climate in which the Yard operates, here is a quickie "Cook's tour." The present industrial accounting system stems from authority of Act of Congress, Public Law No. 207, 81st Congress, dated 4 August (that's the Coast Guard's anniversary date), 1949. The Secretary of Treasury's regulations for the administration of this law became effective 1 July, 1950. The National Security Amendments Act passed a few days later covered the same subject for the other armed forces. I mention this only to show the parallel thinking and the fact that our authority is an entirely separate Act of Congress, which may account for some differences in details of operation.

A special revolving fund, detached from other Coast Guard funds, was set up. An inventory of fixed assets, and supplies and materials on hand, and what amounted to an evaluation of the work load in sight became the parameters of this fund. There was no additional cash outlay, and in this sense the Yard Fund differs slightly from the Navy Industrial Fund. The lack of such a working fund to cushion the variations in our work load demands that operations within the Yard be followed very closely to avoid financial reverses. For instance, in the matter of maintaining our stock of ready-for-issue aids to navigation buoys, we face the situation where because of, say a hurricane, we may have an increased demand for certain types in excess of our stocks, yet we are precluded from manufacturing replacements at once because our immediately available funds are tied up in stocks not being called for. Now, if our revolving fund were larger, or even if we were under the old system of appropriation purchase accounting, we could proceed with the new demand with facility. However, since this would tie up more funds upon which you and I are helping to pay interest, we probably have the best system, economy-wise. We are forced to keep cash assets, as well as stock, as low as operations will permit. The Yard Fund is not a fixed amount, but at current work levels varies between 12 and 16 million dollars.

Orders placed for work at the Yard are covered by an advance of funds according to estimate. Adjustments are made on computed costs by securing additional transfers or making refunds. Obviously, neither profit or loss is permitted, and our surplus, as I mentioned before, is kept at minimal level consistent with offsetting immediately foreseeable losses, such as fiscal year-end diminution of work load with consequently heavy leave taking.

Generally accepted principles of commercial accounting are employed, except that the law precludes inclusion of capital replacement of structures, and there is no tax or insurance problem. A reasonable allowance for depreciation and obsolescence of equipment and tools is included in the indirect charges, along with military management salaries.

The Yard's entire accounting system is so designed as to give segregated costs by specific jobs. These become valuable tools for management. They are yardsticks to be used over and over as similar jobs recur, and they even come in handy to whack a juvenile delinquent, who claims out of line costs when no out of line elements except poor planning or performance can be demonstrated.

A few years ago, they used to put blinders on horses' bridles, the theory being that this made them more manageable. They couldn't see a wild blowing newspaper on a March day or a horseless carriage as it putt-putted up from behind. Among the several things wrong with this system was, the horse couldn't anticipate the whip. You can see how unfair this was, for if he could see you reaching for it, he had the immediate choice of speeding up or receiving the welt first and then speeding up.

I was Planning Officer at the Yard some years back, and I speak from experience when I say it was difficult to get an honest day's work, day after day, job after job, from some of the boys we then had on the waterfront. When confronted by the sometimes less-than-valid accounting figures of those days, the supervisors would just throw up their hands, and we would lose by default. Today, with the more accurate cost figures on what has been done under average conditions, our supervisors will more easily accept pressures for cost reductions, and as I mentioned with the horse, about all you have to do is REACH for the whip, *provided* he knows the whip is there and, sans blinders, he can see you reach for it. We have removed the accounting blinders as best we can, and we all see more of the whole picture. It's better for the horse and it's better for the driver.

Our industrial fund operation might be said to begin anew each year in the making of the annual budget. The Comptroller places a price on our operating plans. This tests their validity by reference to statistics. I'm not going to describe the making of the budget further than to mention that it stems from these principal sources of information: The approved Yard *organization,* involving all its personnel with their graded salaries; the *physical plant,* including tools and equipment, their upkeep, replacement, and obsolescence; the *work load forecast,* the only source of income; and the *material requirements* based on the prospective work load. Each cost center states its requirements and, in turn, is held approximately to the final budgeted amounts. Although the making of the budget is more or less a continuous process, we terminate the crystal-gazing period, and after we have faced east and bowed three times, praying that the blessing of Truth has been upon us, the Comptroller wraps the package up. At this time, there is general good feeling in the management centers. It is as if we have ingested a happiness pill, and its effects last a little while, at least until the second month of the new fiscal year upsets it, and we suddenly recall there *was* conflict between the tea leaves and the crystal ball. But, like the boats we build at the Yard, the budget has actually been well designed

by skilled technicians, interested in their jobs, and put soundly together by master craftsmen. Since its prototypes have already had seven years at sea, we need not fear the tempest. Our budget can be rolled over five times, and with but a few minor repairs, can be made seaworthy again.

I understand that before he became navigator, Columbus was a controller and this experience particularly fitted him for his great role. He didn't know where he was going, didn't know where he was when he got there, didn't know where he'd been when he got back, and he did it all on borrowed money.

Today's comptroller has more sailing directions than Columbus. Recently, I came across a six-part statement of the concept of controllership, approved by the National Board of Directors of the Controller's Institute on 25 September 1949. While I recognize this as an ideal, like the Ten Commandments or the Sermon on the Mount, and that there may be little resemblance between an individual controller and the very ethical controller of the document, it's still a good mark to shoot at, and so I'm going to borrow it. My sights may not be properly boresighted. Even if I get too far out in deflection or over or short, the comptroller will still find this six-target raft a good one to tow.

Some years ago I was engineer officer on one of our destroyers. Our job was to chase rum runners. This kept the price of whiskey so high that the game was profitable for those who were illegally set up in business ashore and at sea. On this particular afternoon, the skipper and the exec. were planning their tactics for the night's operation. As the next senior and as a staff officer I was sitting in. The skipper finally turned to me and said: "Day, I want to make thirty knots and I want all four boilers." With my usual eye to economy, for this was during the depression, and things were tight money-wise—we even tore up our own undershirts for wiping rags—I replied: "Yes, sir, but we can give you that speed easily with three boilers and, in fact, if we leave a little earlier, we can be there at the same time on two boilers at twenty-eight and a half." He scowled, cleared his throat, and then cut loose. This is not the place to quote his exact language, but the polite version ran something like this: "Young man, when I want your advice on how to run my ship, I will ask for it, and until I do, you keep quiet! Now, get out of here! I don't like your eavesdropping anyway." He belonged to the old "line officer" school. From the first, he had been taught and never even considered there was any other attitude for a person in his position except: "Let there be light, and there was light."

A lot of businesses and, as we all know, some military establishments have been run that way in times past. One thing I will say for the system, it got things done. How much it cost was another matter. In fact, no one knew, and it didn't pay to be too inquisitive, either. But time marches on: Enter the comptroller, and the Institute's *concept number one:* "To establish, coordinate and maintain, through authorized management, an integrated plan for the control of operations." In this concept, the staff officer is accorded a place at the planning table and is less likely to be run out of the wardroom upon the offer of an economy. However, it makes clear that the comptroller is still a staff man, and he must be careful not to usurp the line function of the manager. I think, of all the comments I might make on how to get along none could exceed in importance this fact-of-life: The necessity to recognize who is boss. To him who has the final responsibility must go the final authority. His decision is over-riding, and comptrollers, as well as engineer officers, must early learn this lesson, and remember it late. His royal flush of authority can make your four aces of advice look pretty sick.

That reminds me of another incident in my brash young life. This time I was navigator, and as was customary, I brought the Navigator's Notebook to the skipper every morning, or left it on his desk if he wasn't up. On this occasion, I had made an entry "experienced a set of three knots." I was in the middle of my breakfast when the messenger burst in. "The Captain wants to see you right away!" As I stood shaking by his desk, he said, "Young man, your entry here is not correct. I have changed it to read, 'knots per hour'." "But, sir, that would make it acceleration, because a knot is already a unit of speed." In utter disgust, he said, "Go to my big dictionary and look it up." I did. "Here it is, sir . . ." "Just a minute, I'll tell you what it says." And he then proceeded to outline that it was some fraction of the distance from the pole to the equator, etc. "I'm sorry, sir, but that is not what it says here. Here it is under 'Naut. A unit of speed, a nautical mile per hour'." "What, you mean to tell me it says that? Why, what did he know about going to sea? He probably never saw the ocean. From now on you will use knots per hour." "Yes, sir!" and as I got out of the cabin as quickly as I could, I didn't know whether to laugh or cry. I felt like both. I was as confused as if I'd come out of a comptroller's conference. But, one thing I was on my way to learning: Right or wrong, the boss is always right. Maturity and a change of position have taught me another thing: It pays *not* to cut your advisors off too short; they might be right, yes, even if they happen to be young men from the comptroller's division. They might just be able to help us old "fuddy-duddies" away from our trained capacity to overlook what we do not wish to see, or as someone stated it: "Don't confuse me with the facts—my mind's made up!"

While you have been riding along a stretch of new highway construction, do you recall seeing a sort of left-over cone-shaped hill right in the middle of an excavation? Did you ever wonder what its purpose? When a surveyor lays out a grade, he refers to a primary bench mark, and then establishes secondary and tertiary marks for handy reference. That little hill had a surveyor's stake on it. It is part of his system of stakes which have grade marks and distances on them to guide the construction crews who

do the heavy work. Silly as it may look, that stake must remain there, a reference, as long as it is needed. Our budgets are like those stakes on their little hills. Early in the game, and in concert with the engineers and top management, the comptroller views the whole project and by his budget sets the stakes. *How we are doing* is as important to managers in a shipyard as to the engineers on the highway. *How we are doing* has a substantial effect on the final outcome of every job. That is why *concept number two* states: "To measure performance against approved operating plans and standards, and to report and interpret the results. . . ." If his frequent excursions back to his reference stakes indicate agreement, things are either O.K. or maybe he is just a good accountant. But if they fail to check out, then he must start being a comptroller, and fulfill his mission of interpretation. If I am to manage, then I must have the facts, and like the engineer's, I expect the comptroller's to be as reliable.

There was a time, and not very long ago, either, when the only financial appraisal of our projects consisted in adding up all the bills and subtracting from the funds originally apportioned. As frequently as not, there was a negative balance *and then* the scramble to augment the funds and get the account out of the red. That red was somehow, by accusation or inference, reflected in the faces of those who were trying to manage the work and the funds, but never could quite seem to get on top. You remember, I am speaking from experience. We were amateur skiers trying to make an ascent and, between stepping on the opposite ski and sliding backwards half our forward progress, we didn't do so well. Enter the comptroller. With his new business machines and a new concept of service, he has installed a ski-lift up the mountain. Now we can hitch a ride instead of doing it the hard way, and the trip down, our real objective, is pure sport. Oh, I'm not forgetting that there will still be a spill now and then, and we'll turn up with a red place or two. But it will probably be elsewhere than on our faces. Some heavy clothing may have to be removed to get at it. The comptroller—now in the role of doctor—discusses: How did it happen? Where does it hurt? Takes pulse and temperature, watches our reaction as he constructs the little chart at the foot of the bed. Maybe we get a pill, or a shot in the you-know-where to help us chase out the bugs. Had we taken more of his advice, we might not be seeing so much of him now!

There are several kinds of doctors besides horse, and many of them are specialists. If the comptroller hospital is properly staffed, there will be specialists in accounting, budgets, business machines, methods, etc. And just as the modern hospital turns out staff work by all who have seen the patient, so the comptrollers must make up their financial report, and like the medical report, it must be in terms we can understand. And we don't expect an over-simplification like: "The patient died." We hope it will say: "The project is solvent," but if not, then we need his interpretation of what we *did didn't* do. The modern patient-manager (you notice I didn't say impatient) has a right to expect this sort of treatment.

I have a neighbor, the usual kind, a swell fellow with an ideal family of three kids and several pets, including an alley cat of quite uncertain ancestry. Recently, the cat was shot in the thigh, but somehow managed to drag itself home and into a basement window well, where after some searching, it was found by the little girl. After a trip to the vet's, the cat made a routine recovery, but the family is still recovering from the $73.60 bill from the vet. The cat will forget its wound long before Mr. Squire forgets that bill. That's the trouble with unbudgeted items. You never know, cost-wise, how they will turn out, and afterwards, you may think of several other ways you would rather have spent the money. If the alley cat is not worth its probable cost, then perhaps another disposition is in order.

Concept number three calls for a measure and report on the validity of objectives, and consultation with other segments of management for policy or action in pursuit thereof. The comptroller traces the cat's ancestry to help evaluate the situation. The same is true when considering additions to the family, the continuing flow of new ideas, so earnestly sought by management. It is not necessarily indicative of idle dreaming that the round filing cabinet beside the manager's desk gets some of them. It merely means that evaluations have been made; cost disciplines are being enforced; stability and guidance are replacing do-it-as-it-turns-up thinking. Thus, we are not surprised by the bill.

With the arrival of every ship in the Yard, it is customary for the ship's commanding officer to call on the commanding officer of the Yard. Later, the call is returned aboard ship. This is all part of my job as manager, and it involves customer relations. We talk about a number of things, but one subject always seems to crop up—that of finances. Although we have him as a captive customer, and the money he is spending does not come out of his pocket, you may be sure he is interested in getting the most for it. He has to live with the product this money buys, and I might add, as often has to live without what he would like to buy if he had the money. He and the Planning Officer have to make the decisions. But it frequently happens that some jobs are finished sooner or at less expense than anticipated, thus releasing funds for other cherished work. It is important to him that knowledge of the state of his account be current. Here the comptroller is worth his weight in gold for customer relations. Any slowdown knocks him off the gold standard, but fast. This is hardly the "action in pursuit thereof" envisioned by our ideal.

The fourth concept has to do with taxes and reporting to other government agencies. It's written as a quickie, and I'll dispose of it the same way. We are already acquainted with government methods,

and by merely perusing a dozen or so two to three-inch thick manuals and entering a hundred or more pages of changes every year, we can keep right up to date. Remember, the boss expects it of the comptroller. But don't worry, if you make a "boo-boo," the Comptroller General's staff will back you up, even if it takes seven years.

Concept number five has to do with the effect of external influences, and it has less application in military comptrollership, because we have what might be termed a captive trade, and we ourselves are captive to higher governmental pressures. I am going to turn it about and apply the same reasoning to internal influences. Unlike business, as defined in the usual sense, profit is not the motivating force of the government Yard. Yet to say that we are not interested in *all* the motives which normally produce profit would be a far cry from the facts. As a manager, I am intensely interested in securing the maximum output of the highest quality work at the minimum cost. Only a dreamer would expect this attitude to be reflected from supervisor to supervisor on down to the production workman. Somewhere along the line, a mirror is liable to be dirty, or even more likely to be a little out of kelter; hence, the idealistic beam gets lost enroute. Yet if we are to achieve economy in our operations, somehow we must reach the man with the welding hood. It is difficult to speed production; we are forbidden to pay incentive wages. Our men work strictly on a time basis; their output is not a factor in their pay. High quality can be obtained, but seldom speed. The workman is little interested in costs. The country's 72 billion dollar budget seems like a mighty big reservoir compared to his hourly wage. It's like trying to get your family to shut off the tap to stop the drip by saying water costs money. They know it's only a few cents a thousand gallons. Nor do you fare much better by crying "water shortage" when they can look out the window and see it raining. If you get tough, then it's always, "Why pick on me? There are others who waste more than I do."

As keeper of the keys, comptrollers have a role in this difficult task of securing cooperation at the worker's level. With men, and this applies to you and me, all of us, every motion is preceded by emotion. The task before us is to stir up the right kind of emotion. "Nah, I don't wanna!" is the one reaction you are sure to get on the waterfront if you say, "Step lively." But if the production curve fresh posted from the comptroller's office points the way, the leadingman's cheery, "Let's get the job rolling boys," is worth a thousand words. I honestly believe most men would do better if they knew better. How can they know, if the comptroller who is "in the know" doesn't tell them?

I'll bet those of you who grew up on the farm before the days of electric water pumps had to carry water like I did, with a leaky bucket. We seldom had money for a new one. I don't know why we didn't fix the leaks. I guess it was because so many other things seemed more important. If you dilly-dallied along the way, your water mostly leaked out. If you hurried, a stubbed toe—there were no sidewalks then—would cause you to spill the whole thing. Comptrollers, who are not absorbed in carrying the water, ought to be able to view the process objectively and help top management to come up with possible solutions: Fix the bucket, pave the walk, or with an eye to the future, install piping and a pump to eliminate the hand carrying entirely. And they should know the costs and their effects upon the fiscal structure.

The comptroller should be as quick as the production superintendent or the personnel relations man to spot trouble brewing. The story will come to him by a different route, most probably through his figures. To learn, interpret, and report, and suggest a solution is what I expect from the comptroller.

One time I was sent out with a pulling boat and eight men to take water temperatures around an iceberg. At this location, the water was relatively warm, about 60 degrees, and the temperature only dropped a few degrees when right alongside the windward side of the berg. In such warm water, icebergs are very unpredictable, always restless as they melt away. We had worked almost all the way around this big fellow when I said, "This doesn't look good to me. Let's get out of here; give way together!" We stood off about 100 yards or so, and then I gave the boys, "Oars," while I got out my camera to take a picture. I wanted the berg to fill the whole frame, instead of being the usual speck in the middle of a lot of horizon, and this was just the right distance off. But I never got my picture. While I was steadying myself against the boat's motion and looking into the finder, there was a tremendous c—r—a—c—k! followed by a roar as a piece of ice the size of a five-story apartment house came crashing down as the whole berg rolled over toward us. The boys were facing aft and could see the whole thing. They gave way without command. The unexpected lurch almost toppled me and camera over the stern. I grabbed the steering oar and hung on for dear life. Then, glancing back, I saw what the crew had already seen, a huge wall of water overtaking us. Here was real danger and I squared away the boat so as to take the wave perpendicularly. It picked up our stern and rushed us along like a surfboard for perhaps two hundred feet, and then just as suddenly, dropped us. We found ourselves completely surrounded by brash—small pieces of ice from the size of baseballs to chunks twenty feet across. It was now impossible to row. We had to stand the bow oarsmen up, to use their oars as pikes to fend off, and we spent the next fifteen minutes extricating ourselves. You've seen that famous picture of George Washington crossing the Delaware. Well, that's just what we looked like. We may not have been as cold, but we were just as scared. We had had a few anxious moments, but I didn't start to sweat until we discussed that it was just a chance decision of a few moments before that

had saved our lives. We rowed the mile or so back to the ship and ice patrol went monotonously on. I had always wondered why the skipper always kept the ship so far away, especially when I wanted so much to get close-up pictures. Now I knew. Experience had been a good teacher. Let the polar bears and the gulls have the close-up from now on!

I learned more than merely to stay away from icebergs. I learned respect for something so much bigger than myself. I learned that following precedents, rules written in blood by that dear teacher, experience, is a pretty good idea.

Concept six provides for the protection of the assets of the business. The first requirement is to understand what those assets are. Take a row around, and size up what you can see. Then back off a little, to better your perspective. Evaluate the submerged seven-eighths. It's there all right! Thus, you will acquire respect for that of which you are but a small part. I am not talking only about the physical, but about our entire heritage, the "blood, sweat and tears" of our predecessors. *Respect* and *protect* the traditional policies of management, the precedents and the good will which have built our establishment into today's going concern. Responsible teamwork in the public interest is essential. Comptrollers have a vested interest and a clear duty to perform in upholding the moral principles required of Government-in-business.

Now, I didn't learn all this in that exciting moment of eternity when I saw that wave bearing down on top of us. Part of it is maturity. Be conservative in your judgments, and you won't go too far wrong. But a word of caution, too. Don't be an old man before your time, lest you let conservatism stand in the way of progress, and it will. "Without vision, the people perish." Part of that vision is dreaming and scheming, even doing a little exploring in dangerous waters. Take your temperatures as close to your ice mountain as you dare, but never lose respect, lest you be overwhelmed.

I have a friend who was so busy landing an Alaskan salmon he did not take time to watch out for a big brown bear behind him, and who, immediately the fish was landed, took possession of it, while my friend beat a hasty retreat downstream. Preoccupation with accounting, or payrolls, or the complicated modern machines thereof, means withdrawal from overall management viewpoints. I admit it's hard to be looking everyhere at once, but that is where true comptroller staff work comes in, to be lookouts for the interlopers—the profit snatchers—who gobble up the catch, not to mention, scaring the pants off the manager in the bargain. For any period, in retrospect, we need more than a fish story, no matter how interesting it may be. We need fish! While the production department is catching them, and the planning department is luring others into range, and the supply department is bringing up more fishing gear, the comptroller department must be watching and warning. The boss comptroller must be the oversize and complicated lens which puts the combined work of his department on a Cinemascope-sized screen before his management audience.

Comptrollers who are able to live up to the six concepts their own people have written will be pretty close to paragons of comptroller virtue, and will be doing what the top manager expects.

A new electronic brain especially designed for business purposes was demonstrated recently by the Datamatic Corporation. Claimed to be the first machine designed for business use, it is characterized by the ability to process a tremendous quantity of data, performing relatively minimum amounts of computation. This contrasts with computers designed for scientific use, which generally handle relatively small quantities of data and perform highly complex computations.

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"U. S. NAVAL INSTITUTE PROCEEDINGS"

THE U. S. MERCHANT MARINE AND NATIONAL DEFENSE

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OUR national policy today requires that the United States maintain a Navy and Merchant Marine capable of carrying on warfare anywhere in the world. The strategy of naval warfare securing the sealanes against enemy attack in order that shipping can transport forces, materiel, and supplies needed to conquer, occupy, and police enemy territories has not changed appreciably with the passage of time, even though weapons have grown more complex. Secretary of the Navy Gates stated before Congress on July 11, 1957, ". . . A large, modern, and well-balanced American merchant marine is positively vital to our defense planning, as without it, in time of war, neither the military effort nor the war economy of our Nation could be supported . . ."

The U. S. Merchant Marine by 1907 had shrunk so low that when President Theodore Roosevelt sent the U. S. fleet around the world, the Navy was forced to charter foreign flag vessels to serve as auxiliaries.

Only ninety years ago, at the close of the Civil War, the United States turned her back on the seas from which she had drawn her strength for so many years and devoted herself to westward expansion. Men and capital found larger rewards in new fields of endeavor, and the American-flag merchant marine was allowed to dwindle to a fraction of its pre-Civil War size. In 1855 we had carried about three-fourths of our foreign commerce in our own ships. By 1890 we were carrying only one-eighth, and by the outbreak of World War I, carryings in American-flag ships had dropped to about one-tenth of our foreign commerce.

Although the United States in 1913 was one of the world's great exporting and importing nations, it had no more than eight per cent of the world's total of ocean-going vessels of 3,000 deadweight tons or more. In the early days of World War I, a large proportion of the foreign flag merchant fleets upon which we relied to meet our import and export trade was diverted to other trades, laid up in port, or sunk. Our own shipping, plus foreign ships available, soon became inadequate to carry our trade. We were unable to serve ourselves or the nations with whom we were soon to be allied. Three years later, the Shipping Act of 1916 was passed. Recognizing the threat to its economic and military security, the United States then undertook a huge and costly crash shipbuilding program. This program, costing more than three billion dollars, produced 2,300 ships, but only a few of them were delivered before the Armistice, and the quality of most of them was inadequate to meet the competition of newly constructed foreign flag vessels.

In 1920, American merchant ships of 3,000 deadweight tons or more represented 30 per cent of the world's total of such ships, and the United States was in second place in tonnage among maritime nations.

The Merchant Marine Act of 1920 was designed to promote the development of U. S. flag services throughout the world and to assure the maintenance of a strong merchant marine for commerce and defense. The many ships available were to be sold to U. S. citizens, not as surplus, but for the express purpose of organizing new trade routes and continuing to operate essential foreign and coastal services. The Shipping Board, through its Emergency Fleet Corporation, was authorized in the meanwhile to operate the ships on the trade routes until business was sufficiently developed to make feasible the sale of such ships on terms satisfactory for independent private operation. American operators, however, were reluctant to purchase such ships be-

cause of the lack of adequate government assistance, world conditions in general, and the world shipping situation in particular. As a result, the operation and maintenance of the U. S. flag services in foreign trade depended almost entirely on the government operated fleet.

The Merchant Marine Act of 1920 proved seriously deficient in that no provision was included to promote the replacement of obsolete government ships. The 1920 Act did provide for the establishment of a construction loan fund by setting aside, out of Shipping Board revenues, an amount not to exceed $25,000,000 annually during the five years from the signing of the Act. The Thirteenth Annual Report of the U. S. Shipping Board and the U. S. Merchant Fleet Corporation covering the fiscal year ending June 30, 1929, indicates that 69 new ships were constructed under this Act.

For several years following the passage of the 1920 Act, considerable attention was devoted to American merchant marine problems by the Executive and Legislative branches of the government, but there was marked divergence of opinion as to the type and as to the desirability of assistance that should be authorized.

The Jones-White Act was passed in 1928, which confirmed the policy of the 1920 Act, again recognizing that a merchant marine was necessary to the national defense and the promotion of the foreign and domestic commerce of the United States. This Act increased the revolving construction loan fund to $250,000,000 and increased from fifteen to twenty years the period of amortizing construction cost of the ships. Interest was charged at 5¼ per cent for periods during which ships operated predominantly in the coastwise trade and at 3½ per cent when operated predominantly in the foreign trade. This latter was the lowest rate of any government obligation issued after April 6, 1917 (except postal savings). Fifty-eight vessels were constructed under the provisions of the 1928 Act.

The Merchant Marine Act of 1928 set up a system of ocean-mail contracts to aid American flag lines engaged in foreign trade. The compensation provided for carrying the mail was fixed on a mileage basis, with maximum rates varying according to size and speed of the ship. Actually, this legislation was designed to compensate American ship operators for construction and operating costs which were higher than those of their foreign competitors. It was expected that the rates would be high enough to permit the maintenance of American flag services in the face of foreign competition.

The results of our attempt to foster an adequate merchant marine under these Acts are summarized briefly in the statement from a survey made about the time of the passage of the Merchant Marine Act of 1936:

It must be admitted that, despite the millions of dollars lavished on the American merchant marine during the past 15 years (including the payment of a quarter of a billion dollars in mail contracts and other subsidies), the effort, so far as the establishment of a sound merchant marine policy is concerned, has been a failure.*

Congressional recognition of the dangerous inadequacy of the American merchant marine, and Congressional concern over the revealed abuses of the ocean mail contract payment form of indirect aid culminated in 1936, after a period of extensive study of the problems, with the passage of the Merchant Marine Act, 1936, and the creation of the U. S. Maritime Commission.

In the Merchant Marine Act of 1936, Congress established the administrative organization and the administrative authority, which, when supplemented by the necessary appropriations, were designed to assure the construction and the continued maintenance of an adequate and well balanced American merchant marine to promote the commerce and the national defense of the United States.

The express aim and purpose of Congress in the enactment of the 1936 Act is found in the "Declaration of Policy" set out in Section 101 of the 1936 Act, reading as follows:

It is necessary for the *national defense* and development of its foreign and domestic commerce that the United States shall have a merchant marine (a) sufficient to carry its domestic water-borne commerce and a substantial portion of the water-borne export and import foreign commerce of the United States and to provide shipping service on all routes essential for maintaining the flow of such domestic and foreign water-borne commerce at all times, (b) capable of serving *as a naval and military auxiliary in time of war or national emergency,* (c) owned and operated under the United States flag by citizens of the United States insofar as may be practicable, and (d) composed of the best-equipped, safest, and most suitable types of vessels, constructed in the United States and manned with a trained and efficient citizen personnel. It is hereby declared to be the policy of the United States to foster the development and encourage the maintenance of such a merchant marine.

The Merchant Marine Act of 1936, with numerous amendments, and the Ship Sales Act of 1946 today form the basis for maintaining a merchant marine adequate for national defense.

The manner in which this is accomplished is by fostering private shipping through a system of government aid. Two of these aids are especially important. Construction-differential payments as high as 50% of U. S. Government cost may be made to offset lower foreign construction costs. Operating-differential subsidies are granted to approximately 40% of the number of U. S. flag dry cargo ships which comprise about 56 per cent of the U. S. flag vessels operating on established foreign trade routes. This form of subsidy covers wages, subsistence of crew, insurance, maintenance, and repairs not compensated by insurance, to offset lower foreign costs and standards of living. In addition, the Maritime Administration may grant mortgage aid,

* Kennedy Report—November 10, 1937.

mortgage-insurance aid, and trade-in allowance aid to foster new construction.

This is not all. In addition, U. S. flag operators may avail themselves of tax benefits by depositing earnings in construction and special reserve funds. In certain instances, it is possible to obtain rapid tax write-offs under the Defense Production Act of 1950.

During the latter part of 1954, the Administration sponsored Public Law 574, better known as the Tanker Trade-in-and-Build program, in order to improve the quality of the U. S. tanker operating fleet and to provide a reserve of tankers in the National Defense Reserve Fleet.

This resulted in the building of six new larger and higher speed tankers and the acquisition in the reserve fleet of fourteen older type tankers. These reserve fleet ships were being used to relieve the tanker shortage created by the Suez crisis.

The transfer of a U. S. merchant ship to foreign registry must be with the permission of the Maritime Administration. This authority has been used as a means of obtaining new construction in the interest of national defense and a modernized merchant marine. As of August 1, 1957, approximately 53 additional new vessels for U. S. flag registry, mostly tankers, totalling over 2,000,000 deadweight tons, have been contracted for or built in U. S. yards under this program. The new ships built or being transferred will be available to the United States in case of emergency; none may operate on trades forbidden to U. S. ships, nor under any flags or owners except as approved by the Maritime Administration.

More liberal Federal ship mortgage insurance provisions in the law have encouraged the entry of additional private funds into shipbuilding ventures.

In addition to the government aids which have been described, we have one very important type of assistance provided through the so-called 50-50 cargo preference features of the various over-all government aid and relief programs. Briefly stated, the 50-50 provisions require that at least one-half of the ocean cargos resulting from U. S. Government aid and assistance programs, or programs which are underwritten by the U. S. Government, must move in American flag ships. Without this type of assistance, which incidentally the Maritime Administration is mandated to encourage by the Merchant Marine Act of 1936, our all too small tramp fleet would be eliminated entirely.

The Administration is further assisting U. S. flag shipping by engaging in prototype development and research aimed at improving ships and, in particular, engines, hulls, and cargo handling systems.

The Department of Defense and the Department of the Navy are continuously consulting and coordinating their studies with the Maritime Administration as to the size and characteristics of the desired active operating U. S. merchant fleet and the desired composition and readiness of the National Defense Reserve Fleet. This is accomplished through a joint committee called the Marad-Navy Planning Group.

In the past, upon the sudden outbreak of war, we found it necessary to hastily improvise a shipbuilding program. This was not only costly but resulted in the production of improvised ships, limited in their capability to meet modern military needs. It must be recognized that the special characteristics of merchant ships which are desired for ultimate military use must, of necessity, be modified and limited to conform to acceptable requirements for successful commercial enterprise.

The Marad-Navy Planning Group was able to set up a program to go to the Congress of the United States on a joint basis. For the first time a channel was supplied to the Congress through which information of combined Marad-Navy mobilization planning could reach them in understandable language. After receiving the reports of this group, the Congress readily supported bills for a phased construction program of the ships required to assure an active operating U. S. merchant fleet, possessing acceptable defense characteristics up to the numerical limits required to meet the initial needs of the Department of Defense and to provide the means for the orderly replacement of operating tonnage approaching obsolescence.

This is of particular importance in view of the problem of block obsolescence. Since most of our operating ships are war-built, constructed over a short period of time, they will all reach the accepted age limit of twenty years at approximately the same time. It would not be feasible or desirable to replace them all at the same time, which would continue a feast and famine situation in our shipyards.

Many members of Congress, complimentary of the work accomplished, stated that for the first time they had received actual data on the dry cargo ships needed to support our Armed Forces, on the troop transport needs that we might be called upon to face, and on the tanker requirements we may need to supply. Ship speed data, gathered by the Marad-Navy Group, has been of great significance and continues to be of prime importance to planning. The Congress has also supported a proposal that a method be provided for the construction and operation of certain prototype and experimental vessels to serve as a basis for an emergency ship construction program. The work of the Marad-Navy Planning Group is of a continuing nature, resulting in pertinent and current recommendations enlisting the support of the Congress for the rapid modernization of the U. S. Merchant Marine.

Today, our U. S. Merchant Marine, a deterrent to any potential aggressor, is able to say: "We stand ready to deliver the men and the goods. We can deliver them swiftly and in sufficient quantity to make aggression a costly venture, highly unlikely to meet with success."

Maritime-Navy teamwork has proved to be the

key to the solution of many of our problems. The principle of working together that Americans are taught, and which they have grown to respect, is one of the great spiritual assets of our nation. Nowhere is constructive teamwork better illustrated than in the maritime field, nor is there any field where teamwork is more essential to concrete attainment.

Another essential element to the maintenance of a merchant fleet for national defense has been the creation of the same spirit of teamwork between the government and the U. S. maritime industry. The Congress of the United States has materially shared in this atmosphere of dedication toward the proposition of keeping America strong on the high seas.

Recently the Maritime Administrator, in his address before the Annual Merchant Marine Conference, made the following strong policy statement:

Face up to the facts of life; the primary and basic reason for the existence of a subsidy program—construction subsidy or operating subsidy—is national defense. In the over-all picture, the commercial aspects of the merchant fleet are of secondary importance. Do not misunderstand me. I do not wish to indicate that the commercial aspects are to be disregarded, but I do emphasize the fact that the commercial characteristics must be made to accommodate themselves to the defense requirements.

The three principal elements that comprise our maritime mobilization base are, namely, the shipbuilding industry, both active and dormant, and the manpower skills required to man and build the ships. Let us consider each of these three elements in their relationship to the normal, peacetime merchant marine and its mobilization role.

With respect to the active merchant fleet element of our mobilization base, it is our national policy to maintain a strong, well equipped, well balanced, privately owned commercial fleet, manned and operated by U. S. citizens and subsidized to the extent necessary. The numbers and composition of this active merchant fleet as it engages in both foreign and domestic commerce is maintained at a level sufficient to meet the early requirements of mobilization.

In addition to the active fleet, the government, since 1945, has maintained a National Defense Reserve Fleet which is strategically located in lay-up anchorages along the coastal perimeter of the United States.

The National Defense Reserve Fleets of the nation have a stockpile of shipping in excess of 2,000 ships. Of these 2,000 ships, conservatively estimated at an eight billion dollar value, about 1,500 are Liberty ships. The Liberty ship was the workhorse of World War II. It did a fine job in sustaining the "Bridge of Ships" that so materially aided the Allied victory. However, when Marad-Navy security planning began to assess the potential of these vessels, they came to the inescapable conclusion that in the face of modern warfare techniques, especially those represented by enemy submarines, the Liberty ship was a doubtful asset to our national defense.

Actually the data on hand as to their capabilities, speed, sea-keeping qualities and cargo capabilities, if followed out to certain logical conclusions, might have dictated the scrapping of all of our Liberty ships.

National defense requirements were of paramount importance. It was concluded, on the basis of careful study, that experimentation should be initiated to determine the optimum procedure to be followed in the improvement of the Liberty ship. All the available information and the records were reviewed, as well as the requirements listed by the Navy and the Joint Chiefs of Staff, and the practical considerations involving structural characteristics, speed of conversion under emergency conditions, optimum use of manpower, and availability of ships' power plants.

It became apparent rather early that extensive alterations of the cargo-handling gear of the Liberty should be experimented with in order to increase the efficiency of this ship commercially and to enhance its ability to service the new demands of larger tanks, massive new armament vehicles, and other large and complex defense components.

The supply of diesel engines that were being mass-produced for the Rural Electrification program and a gas turbine that was driving locomotives across the Great Divide and pumping gas through pipelines were also examined. Data were assembled on the free piston engine for experimental use. It was also decided to see what could be done with the supply of Victory ship engines that we had in our warehouses.

In this program there were two basic things to be accomplished. First, there was the factor of national defense, and secondly, the Merchant Marine industry of the United States, in the immediate years ahead, faced a vital task of replacing itself as the ships of the U. S. Merchant Marine became obsolescent.

It is necessary to undertake research in behalf of the future of the U. S. Merchant Marine. This is a proper role for government, since such an undertaking would be economically unsound for any of the individual shipping lines. The first of these experimental measures has been completed and shows good promise toward improving the quality of the Liberty ship segment of the Reserve Fleet if it becomes necessary. Under war conditions we believe that these ships can be made serviceable at a minimum expenditure of material and manpower to tide the nation over during the early period before new construction becomes available. Our emergency reengining, hull conversion, and cargo handling rehabilitation programs seek to improve the defense potential of our reserve fleet.

It has been proved possible to increase the speed of these ships from 10 to 16 knots or more, to inaugurate such a program in an emergency. This could fill the gap while a mobilization shipbuilding

program was getting underway and would be a saving in time, manpower, and material, before newly constructed ships come off the ways.

The shipbuilding and ship repair industry forms the second element of our mobilization base. As in the case of the active fleet element, it is the policy of the Maritime Administration to see that there is a privately owned, active shipbuilding industry maintained at a sufficient level of activity so that it will be capable of expanding at the desired rate to permit the activation, conversion, and defensive equipping of the active and reserve fleets. In addition, it is our policy to maintain it in such condition that it will be capable of expanding sufficiently to man government-owned standby shipyards and such new shipyards as may be required to build new ships to support any war effort.

The Maritime Administration engages in combined planning with the Navy to fully utilize both the ship repair and the shipbuilding capabilities of the United States. In order to keep a sufficiently large shipbuilding establishment actively engaged in shipbuilding, steps have been taken to devise measures for building new ships. The trade-in-and-build tanker program, the transfer-foreign-and-build program, and our negotiations with the private shipping industry to accelerate the replacement of their operating fleets are all based on our efforts to maintain an adequate industrial nucleus and employment level in the shipbuilding and supporting industry to meet mobilization requirements.

The shipbuilding nucleus involves active shipyards engaged in the construction of large oceangoing ships, having, at present, 45 ways either occupied or capable of being occupied with construction.

Our mobilization plans call for a round-out of the active commercial yards and the activation of the reserve yards by employment of management cadres created from the assigned active yards. It might be said that new yards have also been planned with sites selected. Prototype shipyard construction plans and drawings have been prepared.

There is a carefully planned coordinated use of United States ship repair facilities. An agreement signed by the Secretary of Defense and the Secretary of Commerce has established a Coordinator for Ship Repair and Conversion so that the conversion, activation, repair, battle damage, and defensive equipping programs of the Navy and the Maritime Administration can be accommodated in the most expeditious manner with the most effective use of the facilities. Our current continuous ship repair program, whereby certain desirable ships earmarked for early activation are periodically placed in private ship repair yards, does two things. It assures us that the ships are maintained, and it provides at least a minimum nucleus work force in the private ship repair industry.

The third element in our mobilization base deals with two aspects of manpower. The ability of any country to defend itself and the things it stands for depends on the amount, quality, and productivity of its manpower. Our first manpower concern has to do with the maintenance of a nucleus of skilled shipbuilding workers in those shipyards which will be required to expand to furnish skeleton organizations for reserve and proposed new shipyards.

Our second manpower concern is the maintenance of a hard core of high quality seafaring personnel, both licensed and unlicensed, to man our shipping. As the persons comprising the pool of trained, but inactive, merchant marine personnel left over from World War II reach the age where they no longer constitute a satisfactory reserve, it will be necessary to have a reserve not too dissimilar from that employed by the armed services. Our training stations, like our reserve fleets and shipyards, are in being and are held in readiness against the day when they may be activated. In the meantime, the Maritime Administration, by providing merchant marine officer training at Kings Point and by assisting the four state maritime academies, provides for additional officers and ratings.

Of course, it goes without saying that we have problems for which there are no readily apparent solutions. Primary among these is the increasing dependence of the United States on foreign sources of petroleum and ores without a corresponding increase in American flag ships to transport those commodities. Efforts are being made to meet this deficiency.

The Korean campaign afforded a good opportunity to evaluate our capabilities. From it we learned that we could activate ships rapidly and that we could operate as we had previously planned as a logistical support auxiliary for the Department of Defense.

The Maritime Administration requirements for shipbuilding and repair, ship operations, and personnel training are given periodic over-all feasibility and mobilization readiness checks under the direction of the Office of Defense Mobilization. Shortages of critical items of manufacture, long-lead-time items and those requiring scarce stockpile raw materials are dealt with by ODM in coordination with the Business and Defense Services Administration of the U. S. Department of Commerce. Where deficiencies in components and production persist, expansion goals are authorized under the Production Act of 1950, and such a device as rapid tax acceleration is used as an incentive for increasing expansion. When so-called incentive measures fail, the government steps in. This was done in the case of the existing shortage in capability to produce ships' turbines and gears.

Under the Defense Production Act of 1950, The Department of Defense, Atomic Energy Commission, and the Maritime Administration are instructed to take all required measures with respect to facilities and production capacity prior to D-Day which are necessary to assure feasibility of their approved mobilization programs.

The Maritime Administration gives technical ad-

vice to the National Security Council and the Defense Mobilization Board as they deal with matters relating to the adequacy of sea transport.

The United States and the members of the North Atlantic Treaty Organization, through the Planning Board for Ocean Shipping, have agreed to pool shipping in excess of actual military support requirements. The Maritime Administration has assumed the leading role in the planning and consultation which resulted in the present organization and operational procedure of PBOS.

The maintenance of a U. S. Merchant Marine adequate for both trade and national defense is costly and complicated. The high cost of United States shipbuilding and high cost of ship operation in peacetime makes it essential that we devise aids to private industry in order that this essential arm of our national defense can be preserved and that we are not forced to maintain a government owned and operated merchant fleet.

Thus our efforts in recent years have vastly improved the government's role in the joint task of maintaining an adequate merchant fleet under our flag. In our research and development programs, we are not only devising plans for utilizing existing shipping and shipping facilities, and in planning for mobilization expansion, but in addition we are providing a broad base for future commercial development along new technological lines.

The successful use of gas turbines and new type cargo gear in our Liberty Ship experimental program opens new vistas for commercial ship design and subsequent improvement for war use, but it is in the area of nuclear power that the government's role will be most telling in its effect on future merchant ship and propulsion power design.

The Maritime Administration and the Atomic Energy Commission are now carrying out the President's desires and the will of the Congress in constructing the world's first nuclear-powered merchant ship. At the same time the Maritime Administration is engaged in study programs to keep abreast of the swiftly developing events in this field so as to be ready to adapt them for the improvement of merchant ship propulsion design and to the service of our national defense.

"It seems incredible to me that anyone could argue seriously or with justification that new concepts of warfare obviate the necessity of further fostering a merchant navy. I assure you that such views are not held by the Joint Chiefs of Staff . . . If the catastrophe of a general war should be forced upon us by the necessity of retaliation against a surprise attack, the merchant marine, after the initial period of devastating nuclear exchange, would play a most vital role. Indeed, it might very well be the one source of strength of the Free World which would pluck victory from chaos."

—quoted from a letter from the Chairman of the Joint Chiefs of Staff to Sen. John Marshall Butler, as reported in "Marine Engineering/Log," December 1957

HENRY W. PHILLIPS

TALOS DEFENSE UNIT—AN ADVANCED SURFACE-TO-AIR GUIDED MISSILE SYSTEM

ACKNOWLEDGEMENT

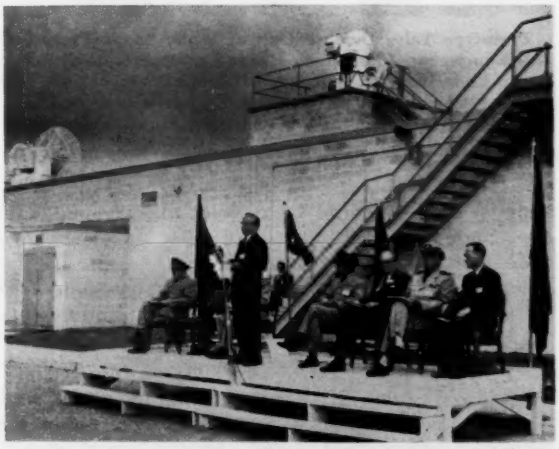
The article written by Henry W. Phillips, Coordinator, Talos Projects, Missile and Surface Radar Department, Radio Corporation of America, Moorestown, New Jersey, is published as of timely interest to readers of The Society.

On October 15, 1957, a prototype Talos Defense Unit was completed at the White Sands Proving Ground by the Radio Corporation of America and turned over to the Department of Defense.

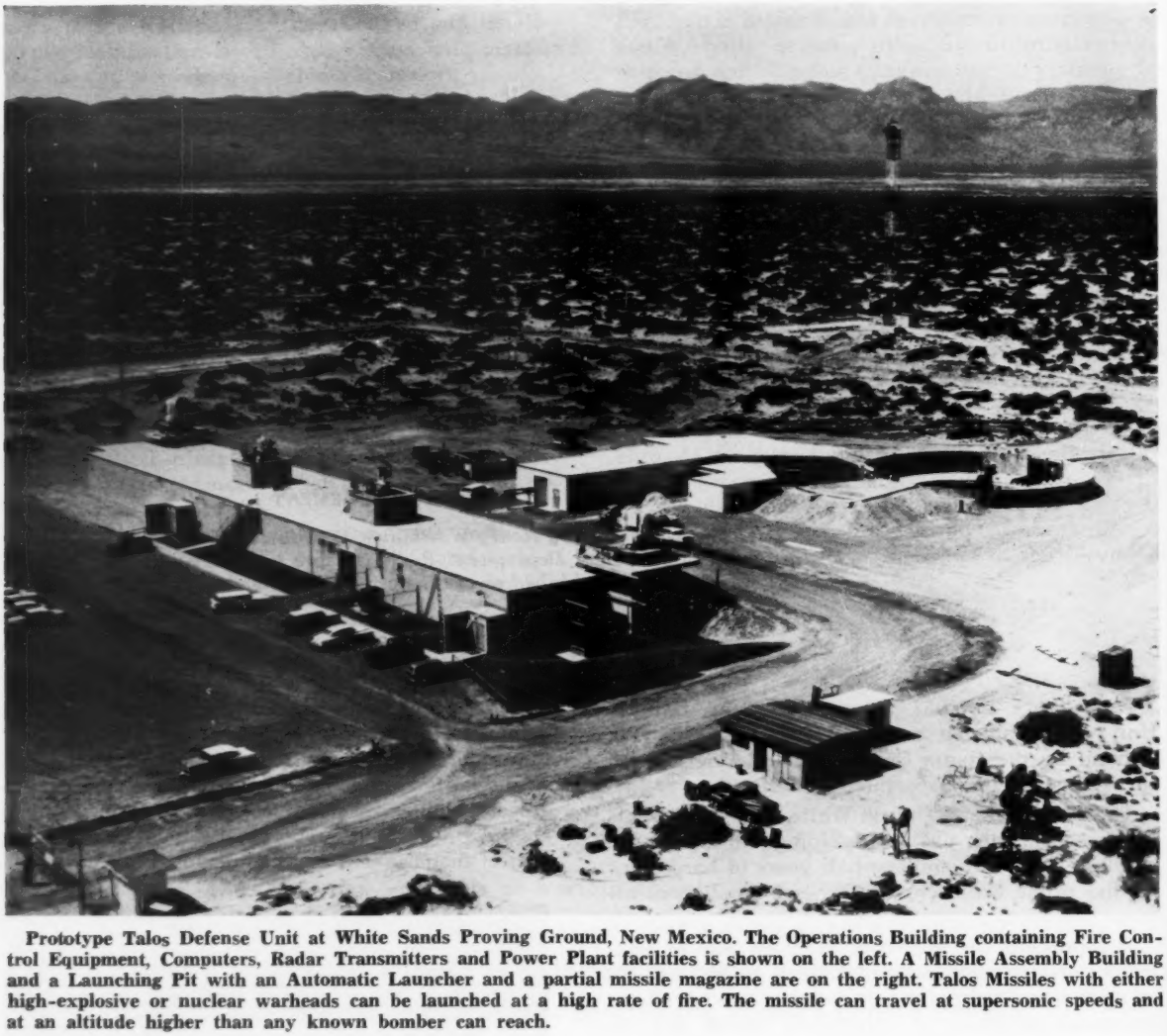
The Talos Defense Unit at White Sands represents far more than the physical building and equipment resulting from two-and-one-half years of hard work by the prime contractor, RCA, and its subcontractors.

It represents the impact of the New Age of electronics and automaticity on military equipment and its operators. During the past decade there have been enormous advances in electronics which are reflected in improved designs of computers, data-handling equipment, radars, missile-guidance systems and tactical fire-control centers. There have been great advances in the design of automatic machinery using electronic controls; and also in automation for production of all kinds of electronic and mechanical equipment which provides for rapid production, low cost, and ease of maintenance. All of these advances in electronic and automatic machinery design techniques have resulted in newer and better tools for the engineer to use in designing a modern weapon system which must be effective and highly reliable, as well as be economical in cost and require a minimum number of personnel of a caliber that can be made available in the ranks of the services.

RCA was awarded the prime contract in early 1955, to develop a Tactical Talos Land Based System and to construct the Talos Defense Unit at White Sands. This presented a challenge to RCA to demonstrate the application of the techniques of the New Age to an important missile weapon system for the defense of our country. It provided an opportunity to use the Project Approach whereby people in highly specialized skills, including technical systems engineers and experts in electronics and mechanical engineering, could be coordinated by a hard hitting project management team to demonstrate how such



Talos Defense Unit at White Sands Proving Ground is turned over to the Department of Defense October 15, 1957. Dr. E. W. Engstrom, Senior Executive Vice President, Radio Corporation of America, is shown delivering the Turnover speech at White Sands. The Talos Operations Building is shown in the background. During speech, Dr. Engstrom stated, "This goes one step beyond pushbutton warfare, for at the Talos Defense Unit you don't even need to push a button to send this weapon into action." The Talos Defense Unit is described as the first completely automatic system for firing and guiding missiles to their targets.



Prototype Talos Defense Unit at White Sands Proving Ground, New Mexico. The Operations Building containing Fire Control Equipment, Computers, Radar Transmitters and Power Plant facilities is shown on the left. A Missile Assembly Building and a Launching Pit with an Automatic Launcher and a partial missile magazine are on the right. Talos Missiles with either high-explosive or nuclear warheads can be launched at a high rate of fire. The missile can travel at supersonic speeds and at an altitude higher than any known bomber can reach.

a major system could be developed, designed, and constructed, in a minimum of time. It provided a challenge and opportunity for the American Machine & Foundry Co., RCA's close associate and principal subcontractor, to apply its skill in developing and producing an automatic missile launcher.

In view of the advances that are being made by potential enemies in developing higher speed and longer range offensive weapons, the time factor for defensive action is lessened. As the speed of airborne targets is increased it no longer is feasible for one human brain or a group of human brains to control and carry out a tactical defense operation. It has become necessary to use automatic electronic and mechanical equipment for data handling, problem computation, and actual missile firing and guidance to the target; while humans are used for monitoring the equipment and injecting elements of judgment when necessary to support the electronic system in its automatic operation.

The Talos Land Based System is an automatic defensive, surface-to-air weapon system which has as its primary function the efficient protection of our military bases and industrial centers against air threats—both subsonic and supersonic. The weapon system, to contribute effectively to the survival of our Nation in event of enemy attack, must not only kill enemy targets but it must provide a maximum of protection at a minimum investment using a minimum of operating personnel.

Three major factors contributing to efficient protection are *coverage*, *rate of fire*, and *kill probability* per missile salvo.

Coverage depends upon both range and altitude. The range of Talos is sufficiently long that each Defense Unit around a city or military base can par-

Automatic Talos Launcher shown with a specially instrumented Talos Missile. Each missile is stored in a reinforced concrete storage cell within circular magazines. During a tactical engagement, signals are received at the launcher, which automatically rotates to the proper missile storage cell. A cart runs from the launcher into the cell, picks up the missile and transfers it to the launcher. The missile remains on the cart while the launcher automatically slews and elevates to the proper position for firing, based on computed information indicating the target position. At the proper time the firing signal is automatically received at the launcher and the missile is fired to intercept the target. The launcher is equipped with anti-icing devices to provide for operation in extremely cold weather.

ticipate in engaging a threat from any direction. This range, coupled with high and low altitude capabilities, gives Talos the greatest coverage of any local defense system in existence.

A high rate of fire is attained by using early warning information from radar networks for mid-course guidance and by time-sharing of major components of the system. This is referred to as multiplexing.

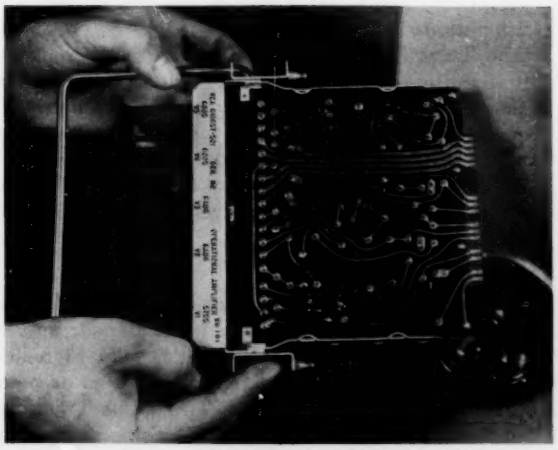
Multiplexing makes it possible for one Talos Defense Unit to engage various targets simultaneously with many missiles in the air at the same time. It can continue to fire single and multiple missile salvos at a high firing rate for an extended period of time.

High kill probability is assured by high overall system accuracy and war-head lethality using either high explosive or nuclear warheads.

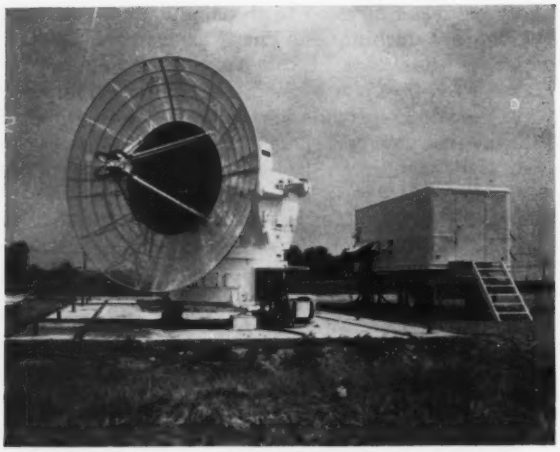
In the design of the Talos Defense Unit extensive effort has been devoted to the application of human engineering techniques. The Fire-Control Center, which is the heart of the Talos Defense Unit, is manned by only a few people at human-engineered consoles which provide displays of information so that the operator can easily observe and monitor the operation. The main fire-control console shows a continuous picture of the status of a multitude of engagements simultaneously. To provide an effective display, a three-color video display screen based on color TV techniques for this important tactical application, has been used.

The Talos Defense Unit includes automatic personnel exercising and system checkout equipment for the overall system. It also includes automatic checkout equipment for the missile.

The automatic personnel exercising equipment is a necessity in a modern weapon system to assure maximum operator training and maximum system readiness in event of an attack. The personnel exercising portion of the system uses a variety of tactical problems, predetermined and recorded on tape. The tape is played back to feed simulated tactical engagement data to the system. The system responds automatically in the same manner that it would during an actual enemy attack. Operators can become closely familiar with the operation of the equipment under various conditions, and the operation of the equipment itself can be checked. The automatic system checkout and missile checkout equipments provide for rapid testing of the complete installation. In case a trouble exists, it is quickly isolated and can be corrected by replaceable printed circuit modules in the system or by replaceable packages in the missile.



Typical Replaceable, Plug-in, Printed Circuit Module. Automatic Talos Defense Unit Check-out equipment and Automatic Missile Check-out equipment provide for rapid testing of the complete Talos Installation. In case a trouble exists, it is quickly isolated and corrected by use of replaceable, plug-in, printed circuit modules in the system or by replaceable packages in the missile. Replaceable modules are produced by RCA automation techniques.



Precision Instrumentation Radar—AN/FPS-16. Developed over a period of 10 years, this reliable, long-range radar provides a means for advanced operational features in the Talos Defense Unit.

Some additional advanced features of this system are as follows:

Missile Interchangeability

The Talos Defense Unit for the Army uses the Talos missile which is identical to the missile which was developed by Applied Physics Laboratory of Johns Hopkins University and produced by Bendix for use by the U. S. Navy for shipboard Talos installations. The missiles use either high explosive or nuclear warheads. The joint use of the same missiles and warheads by the Army and the Navy for land and shipboard systems results in improved economy of the overall Department of Defense program.

Automaticity

The Talos Defense Unit is capable of automatically handling, loading, and launching the missile which eliminates the necessity of personnel in the launching area. The launcher mechanism is almost human in its movement and operation.

In full automatic operation, the Talos Defense Unit operators merely observe and monitor the performance of the equipment.

High Accuracy

By using precision radars, electronic computers, programmed beam-riding missile guidance, and a precise missile homing seeker, extremely high accuracy at short and long ranges as well as at high and low altitudes is provided. The Talos Tracking Radar uses the basic design of RCA's precision, long range, high power instrumentation radar (AN/FPS-16) which has been tested by the U. S. Bureau of Standards and found to be the most accurate radar in existence.

High Reliability

By the use of highly reliable components, redundancy, multiple data channels and automatic fault bypass features, high reliability is attained.

Maximum Safety

The Talos Defense Unit has been designed to provide a maximum of safety to operators as well as to nearby installations. Provision has been made so that missiles can be programmed to provide for boosters to fall in selected areas.

Future Outlook

The basic design of the Talos system provides for the extension of capabilities with a minimum of modification to assure that the system will have continued effectiveness against present and future hostile threats.

RCA is proceeding under the direction of Army Ordnance to demonstrate and evaluate the Talos Defense Unit. Engineers are confident that all of its features, some of which have been mentioned above, and others which have been omitted for security reasons, will soon be demonstrated. The Talos Defense Unit which is at White Sands is a partial tactical system which has been constructed to demonstrate the features required in such an important defense system. In the interest of economy RCA constructed only these items necessary to prove overall system performance. RCA carried out all work to complete the installation on an assigned tract of land. The work included architect and engineering design of site and buildings; construction of buildings; as well as equipment development, production, installation and tests at White Sands. Several launcher firing tests have been successfully made and final acceptance tests were recently completed.

All of the military people in the Army, Navy, and Air Force, the RCA people and the people of the many subcontractors who have worked on the Talos project have certainly met the challenge which was given to them in early 1955 by developing and constructing the prototype installation in 33 months. All who have contributed to this program are looking forward to the day when the Army will present another challenge to deliver a quantity of Talos Defense Units to the Army for field employment to fulfill the mission for which the system was engineered.

COMMANDER S. R. HELLER, JR., USN

NATURAL FREQUENCIES OF SHAFT STRUTS

THE AUTHOR

an Engineering Duty Officer of the United States Navy, was graduated from the University of Michigan with degrees in Naval Architecture and Marine Engineering and in Mathematics. Following graduation he was employed by the New York Shipbuilding Corporation. On entry into the U.S. Navy he was ordered to the Norfolk Naval Shipyard and assigned to carrier construction. After World War II he was ordered to the Massachusetts Institute of Technology for postgraduate instruction leading to the degrees of Naval Engineer and Doctor of Science in Naval Architecture. Since that time he has been Assistant for Aircraft Carriers in the Hull Design Branch of the Bureau of Ships, Maintenance Officer on the Staff of Commander Amphibious Group ONE, and is now Structural Mechanics Officer at David Taylor Model Basin.

INTRODUCTION

DURING the design of *Forrestal* (CVA59) the rather long unsupported lengths of the main propeller-shaft strut arms seemed a potential vibration hazard. Although there had been no prior history of vibratory troubles with these components, the importance and financial investment of *Forrestal* required assurance of safety. Accordingly, New York Naval Shipyard (Material Laboratory) conducted a vibration generator survey of the main shaft struts of *Bennington* (CVA20) to determine the natural frequencies of the strut arms, both in air and submerged. The findings were never made generally available.

Unpublished memoranda prepared in the Bureau of Ships generalized these data into design information. The constraint conditions of the strut arms were likened to those for a fixed-hinged beam; the mass of entrained water was treated as about one-half the mass of the strut arm. Somewhat later the shaft struts of both *Forrestal* and *Saratoga* (CVA60) were surveyed, and the results reported, (1) and (2).* Reference (1) is not generally applicable to the problem since the strut construction in *Forrestal* is markedly different from that in *Bennington*. Reference (2), however, is quite pertinent since strut construction is similar, but the numerical results from *Saratoga* did not seem to agree directly with those from *Bennington* either as to constraint conditions or entrained water.

It appeared appropriate to develop an analytic solution to the problem which might reconcile the differences between *Bennington* and *Saratoga*. It is this aspect with which this paper is concerned.

* Numbers in parentheses refer to the Bibliography at the end of this paper.

THEORETICAL DEVELOPMENT

When shear deflection, rotary energy, and longitudinal forces are neglected, the amplitude equation of lateral vibration of a straight beam of constant cross section is:

$$EIy^{IV} - \mu\omega^2 y = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

with the solution (3):

$$y = C_1(\cos kx + \cosh kx) + C_2(\cos kx - \cosh kx) + C_3(\sin kx + \sinh kx) + C_4(\sin kx - \sinh kx) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where E is Young's modulus

I is moment of inertia

$$k^4 = \frac{\mu\omega^2}{EI}$$

μ is mass per unit length

ω is natural frequency which depends on the boundary conditions.

Figure 1 shows the typical shaft strut construction. Figure 2a shows an idealized form of the strut which will be treated analytically. The hinged support which replaces the strut barrel and shaft was chosen for simplicity. It is realized that this represents a stiffer support than the axial stiffness of the strut arms, but the extremely small amplitudes at the barrel reported in (2) lend validity to the assumption. The fixed ends in Figure 2a must be stiffer

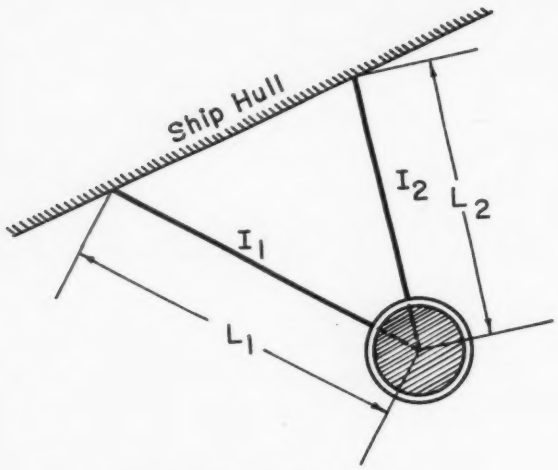


Figure 1. Typical Shaft Strut.

than the actual construction; also the rigid connection between arms must be stiffer than the strut barrel. The combination of these assumptions must yield frequencies somewhat higher than actual because of increased stiffness.

It is also of interest to note that the idealized system of Figure 2a is the equivalent of the system of Figure 2b: a beam fixed at either end and continuous over an external simple support. The solution given herein is also applicable to structures of the type shown in Figure 2b.

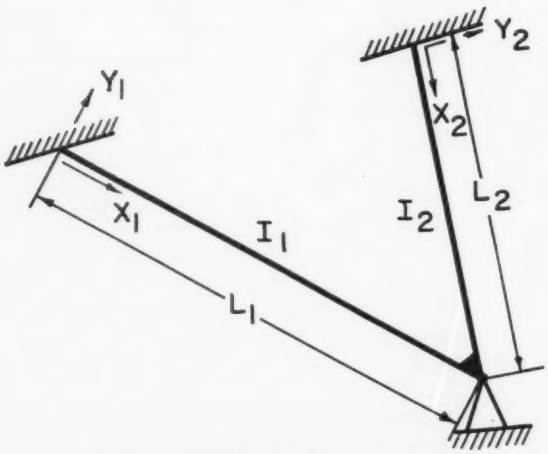


Figure 2a. Idealized Shaft Strut System.

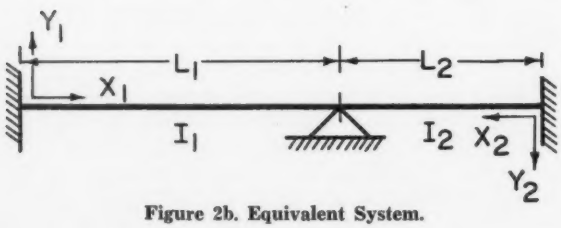


Figure 2b. Equivalent System.

The evaluation of the constants in Equation [2] depends on the boundary conditions imposed. The boundary conditions corresponding to both Figures 2a and 2b are:

(a) $y_1 = 0$ at $x_1 = 0$
(b) $y_2 = 0$ at $x_2 = 0$
(c) $y_1' = 0$ at $x_1 = 0$
(d) $y_2' = 0$ at $x_2 = 0$
} Fixed ends

(e) $y_1 = 0$ at $x_1 = L_1$
(f) $y_2 = 0$ at $x_2 = L_2$
} No displacement at joint

(g) $y_1'\big|_{x_1 = L_1} = y_2'\big|_{x_2 = L_2}$ Rigid connection at joint

(h) $y_1''\big|_{x_1 = L_1} = -\,y_2''\big|_{x_2 = L_2}$ Simple support, no external moment

where the prime symbol (') indicates differentiation with respect to x. From boundary conditions (a) and (b), $C_{1_1} = C_{1_2} = 0$. Also, from boundary conditions (c) and (d), $C_{3_1} = C_{3_2} = 0$. Thus, for a beam with one end fixed, the amplitude equation becomes:

$$y = C_2(\cos kx - \cosh kx) + C_4(\sin kx - \sinh kx) \quad \ldots\ldots (2a)$$

Application of boundary conditions (e) and (f) yields:

$$-\frac{C_{2_1}}{C_{4_1}} = \frac{\sin k_1L_1 - \sinh k_1L_1}{\cos k_1L_1 - \cosh k_1L_1}$$
$$-\frac{C_{2_2}}{C_{4_2}} = \frac{\sin k_2L_2 - \sinh k_2L_2}{\cos k_2L_2 - \cosh k_2L_2} \quad \ldots\ldots (3)$$

Next, the application of boundary condition (g) and Equations [3] gives:

$$\frac{1 - \cos k_1L_1 \cosh k_1L_1}{\cos k_1L_1 - \cosh k_1L_1} = \frac{C_{4_2}}{C_{4_1}} \cdot \frac{k_2}{k_1} \cdot \frac{1 - \cos k_2L_2 \cosh k_2L_2}{\cos k_2L_2 - \cosh k_2L_2} \quad \ldots (4)$$

Finally, from boundary condition (h) and Equation [4], the characteristic or natural-frequency equation is:

$$\frac{\sin k_1L_1 \cosh k_1L_1 - \cos k_1L_1 \sinh k_1L_1}{1 - \cos k_1L_1 \cosh k_1L_1} =$$
$$-\frac{k_2}{k_1} \cdot \frac{\sin k_2L_2 \cosh k_2L_2 - \cos k_2L_2 \sinh k_2L_2}{1 - \cos k_2L_2 \cosh k_2L_2} \quad \ldots (5)$$

The k's are related by the frequencies. Since a common frequency is sought, $\omega_1 = \omega_2$. Then:

$$k_1^2\sqrt{\frac{E_1I_1}{\mu_1}} = k_2^2\sqrt{\frac{E_2I_2}{\mu_2}} \quad \ldots\ldots (6)$$

The ratio $\frac{k_2}{k_1}$, used in Equation (5), has the following forms:

a. Different materials and different cross sections:

$$\frac{k_2}{k_1} = \sqrt[4]{\frac{E_1}{E_2} \cdot \frac{\gamma_2}{\gamma_1} \cdot \frac{r_1^2}{r_2^2}} \quad \ldots\ldots (6a)$$

where r is the radius of gyration of the cross section and γ is the specific weight of the material.

b. Same material but different cross sections:

$$\frac{k_2}{k_1} = \sqrt{\frac{r_1}{r_2}} \quad \text{.....(6b)}$$

c. Same material and same cross section:

$$\frac{k_2}{k_1} = 1 \quad \text{.....(6c)}$$

To obtain a solution of Equation [5] it is convenient to employ an artifice:

$$\text{Let } \phi = \frac{\sin kL \cosh kL - \cos kL \sinh kL}{1 - \cos kL \cosh kL}$$

Then Equation [5] becomes:

$$\phi_1 = -\frac{k_2}{k_1}\,\phi_2 \quad \text{.....(5a)}$$

In Figure 3, ϕ is plotted against kL with the negative branches also plotted positive in the dashed form. The solution is obtained by entering Figure 3 with a given value of ϕ and finding a corresponding value of k_1L_1 from a positive branch. Associated with this is a modified negative value of $\phi\left(-\frac{k_2}{k_1}\,\phi\right)$ and a corresponding value of k_2L_2 from a negative branch. Figure 4 represents a number of such solutions for $\frac{k_2}{k_1} = 1$. These solutions are plotted as $\frac{L_2}{L_1}$ against kL_1. Figure 5 represents the first two modes for the most representative cases for which $\frac{L_2}{L_1}$ is in the range from 0.7 to 1.0.

CHARACTERISTICS OF SOLUTIONS

Some of the characteristics of ϕ deserve further discussion. The numerator of ϕ and hence ϕ itself have zeros when:

$$\sin kL \cosh kL - \cos kL \sinh kL = 0 \quad \text{.....(7a)}$$

This corresponds to:

$$\tan kL = \tanh kL \quad \text{.....(7b)}$$

or the frequency equation for a uniform beam fixed at one end and simply supported at the other. The denominator has zeros, and hence ϕ becomes infinite when:

$$\cos kL \cosh kL = 1 \quad \text{.....(7c)}$$

or the frequency equation for a uniform beam fixed beam.

Special significance is attached to solutions of Equation (5) obtained at zeros of ϕ from branches adjacent to the zeros. These solutions are for con-

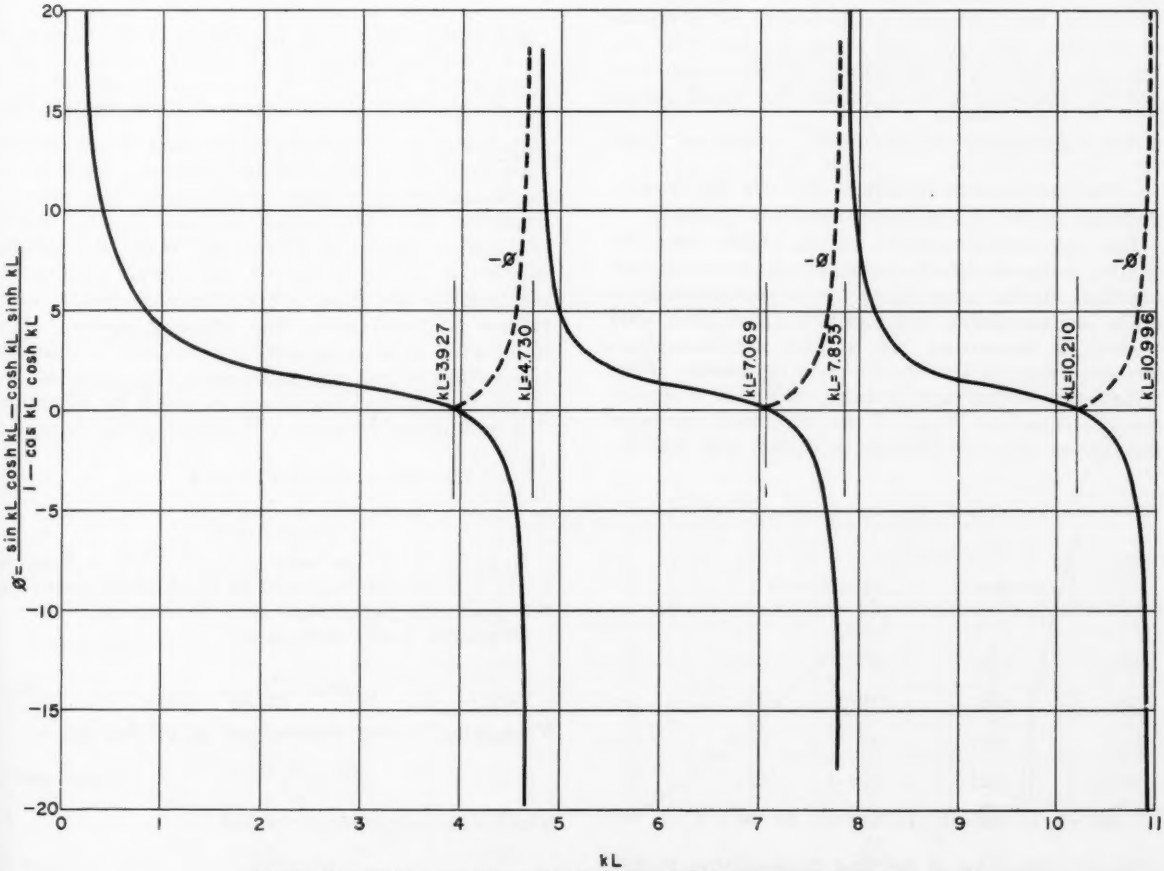


Figure 3. ϕ vs kL—An Aid to the Solution of the Frequency Equation.

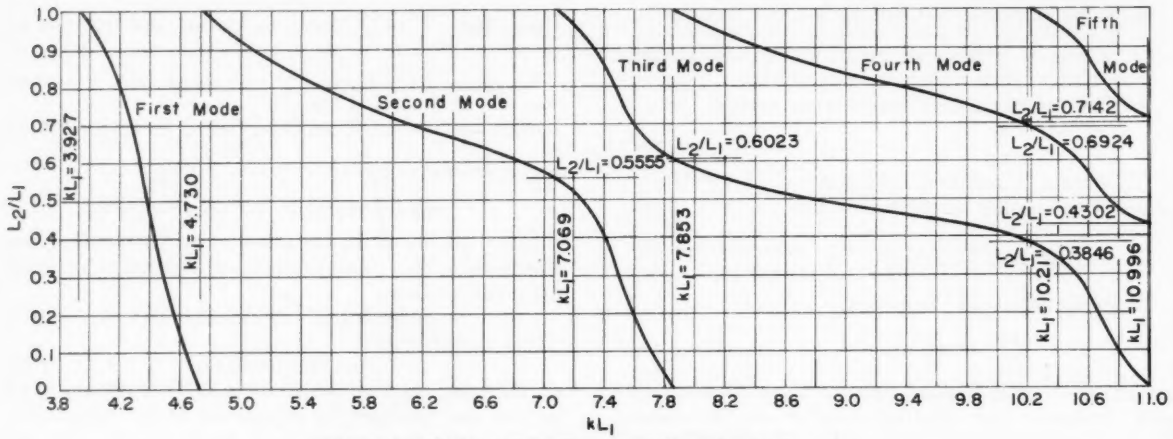


Figure 4. Solutions of the Frequency Equation for $k_1 = k_2$.

secutive *odd* modes for equal length arms (or equal length spans) regardless of the value of $\frac{k_2}{k_1}$, whereas consecutive solutions of Equation (7b) are for the consecutive modes of a uniform beam fixed at one end and simply supported at the other. Similarly, there is special significance for solutions of Equation (5) obtained at asymptotes from the branches adjacent to the asymptote. These solutions are for consecutive *even* modes for equal length struts regardless of the value of $\frac{k_2}{k_1}$, whereas consecutive solutions of Equation (7c) are for the consecutive modes of a uniform fixed-fixed beam.

For the special case of equal length arms the shapes of the amplitude curves for the two arms are identical. As the ratio of arm lengths decreases from unity, corresponding to ϕ increasing from zero (odd modes) or decreasing from infinity (even modes), the amplitude in the shorter arm decreases. When a transition to two new branches of Figure 3 occurs, the characteristic shape of the amplitude curve in the shorter arm also changes in such a way that the number of points of zero slope of the tangent is decreased by one. Obviously, the number of possible shapes of the amplitude curve for the shorter arm corresponds to the mode number. Table 1 summarizes the ranges and shapes for $\frac{k_2}{k_1} = 1$.

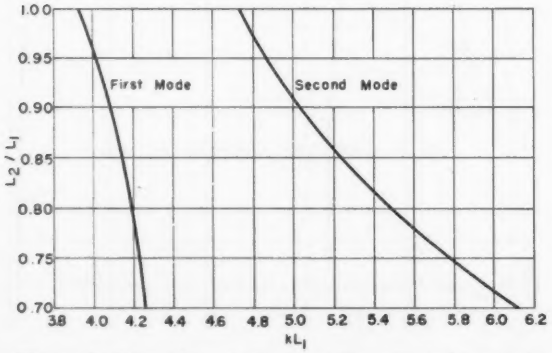


Figure 5. Expansion of the Most Representative Portion of Figure 4.

Solutions for $\frac{L_2}{L_1} = 0$, regardless of the value of $\frac{k_2}{k_1}$, always have frequencies and mode shapes corresponding to a uniform fixed-fixed beam. There appears to be a physical inconsistency here for a single-arm strut, but this is explainable by boundary condition (d). The actual physical system being analyzed is shown in Figure 2b. When the simple support is moved to $x_2 = 0$, the simple support is replaced by the fixed support and the beam must behave as fixed-fixed. The physical system of a single-arm strut is probably more like a uniform beam fixed at one end and simply supported at the other, the solution for which is given by Equation (7b) and hence the zeros in Figure 3 or the values of $\frac{L_2}{L_1} = 1$ for odd modes in Figure 4.

APPLICATION

In order to use the solutions presented in Figures 4 and 5, a relationship must be established involving the pertinent parameters and dimensions.

Originally k was defined as:

$$k^4 = \frac{\mu\omega^2}{EI} \quad \text{.....(8a)}$$

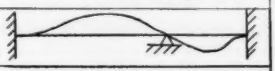
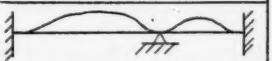
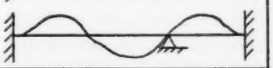
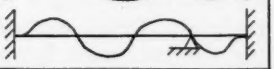
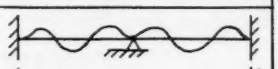
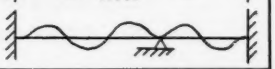
Frequency is then determined by solving for ω:

$$\omega = k^2\sqrt{\frac{EI}{\mu}} \quad \text{.....(8b)}$$

which can be further simplified to:

$$\omega = k^2 r\sqrt{\frac{Eg}{\gamma}} \quad \text{.....(8c)}$$

TABLE 1—*Regions and Mode Shapes for System with* $k_1 = k_2$

Mode	kL of Branches		Range of $\frac{L_2}{L_1}$	Mode Shape
	Positive	Negative		
1	0 to 3.927	3.927 to 4.730	0 to 1.0	
2	4.730 to 7.069	3.927 to 4.730	0.5555 to 1.0	
	0 to 3.927	7.069 to 7.853	0 to 0.5555	
3	4.730 to 7.069	7.069 to 7.853	0.6023 to 1.0	
	7.853 to 10.21	3.927 to 4.730	0.3846 to 0.6023	
	0 to 3.927	10.21 to 10.996	0 to 0.3846	
4	7.853 to 10.21	7.069 to 7.853	0.6924 to 1.0	
	4.730 to 7.069	10.21 to 10.996	0.4302 to 0.6924	
5	7.853 to 10.21	10.21 to 10.996	0.7142 to 1.0	

Since we are primarily concerned with steel and the English system of units, Equation [8c] is put in its most useful form:

$$f = 193 \frac{(kL_1)^2 r}{\left(\frac{L_1}{100}\right)^2} \quad \text{.....(8d)}$$

where f is frequency in air, cpm
L_1 is length of longer arm, in.
kL_1 is the value taken from Figure 4 or 5 for the appropriate value of $\frac{L_2}{L_1}$.

The available experimental frequencies in air and the corresponding theoretical frequencies are summarized in Table 2.

EFFECT OF ENTRAINED WATER

It has long been known that a system vibrating in water moves with it a certain mass of water which effectively increases the mass of the system and consequently reduces the frequency under that in air. The shaft-strut system is no exception.

Although the precise distribution of the entrained water is unknown, the effect can be approximated by considering a cylinder of water surrounding the arm of diameter equal to the maximum dimension of the cross section. The ratio of the masses can be expressed by:

$$\frac{\mu_w}{\mu_a} = \frac{\pi D^2}{4A} \cdot \frac{\gamma_w}{\gamma} - \frac{\gamma_w}{\gamma} + 1 \quad \text{.....(9a)}$$

where A is area of cross section

TABLE 2—*Comparison of Theoretical and Experimental Frequencies in Air*

Ship	L_1, in.	L_2, in.	r, in.	$\frac{L_2}{L_1}$	kL_1	Frequency, cpm		Percent Dif.
						Theory	Exp.	
Bennington	164	122	1.295	0.744	4.235	1666	1725	− 3.42
	140	136	1.295	0.972	3.978	2018	1875	+ 7.63
Saratoga	160	127	1.533	0.794	4.197	2035	1980	+ 2.78
	278	237	1.962	0.853	4.143	842	890	− 5.39
	278	237	1.962	0.853	5.228*	1341	1500	−10.6
	128	115	1.533	0.899	4.09	3019	2640	+14.35
	273	254	2.166	0.931	4.047	918	870	+ 5.52

* Second mode.

D is diameter of the cylinder

γ_w is specific weight of water, and

the subscripts "a" and "w" refer to air and water respectively.

For shaft struts we are usually concerned with sea water and steel. Equation (9a) then reduces to:

$$\frac{\mu_w}{\mu_a} = 0.8694 + 0.1026\,\frac{D^2}{A} \quad \ldots\ldots\ldots (9b)$$

It has long been naval practice to use struts of airfoil section with a chord-thickness ratio of six. With this additional condition Equation (9b) reduces to:

$$\frac{\mu_w}{\mu_a} = 0.8694 + \frac{0.6155}{K} \quad \ldots\ldots\ldots\ldots (9c)$$

where K is a factor depending on the shape of the strut. For the standard strut section (4), K=0.701; for the Taylor Model Basin "Ellipse-Parabola-Hyberbola" (EPH) section, K=0.747. Consequently, for the two most frequently used cross sections, Equation (9c) becomes:

$$\frac{\mu_w}{\mu_a} = 1.6474 \text{ for "Standard Strut"} \quad \ldots\ldots (9d)$$

$$\frac{\mu_w}{\mu_a} = 1.6934 \text{ for EPH}$$

Equation (8b) indicates that frequency is inversely proportional to the square root of mass per unit length. Since the constraint conditions do not change with immersion in water (only the mass per unit length), the following relation must exist:

$$\frac{f_a}{f_w} = \sqrt{\frac{\mu_w}{\mu_a}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where the subscripts "a" and "w" refer to air and water respectively. Combining Equations (9d) and (10) yields

$$\frac{f_a}{f_w} = 1.2835 \text{ for "Standard Strut"} \quad \ldots\ldots (11)$$

$$\frac{f_a}{f_w} = 1.3013 \text{ for EPH}$$

Scant experimental evidence is available for comparison. Measurements on one pair of struts in water are reported in (2). Theoretical and experimental frequencies for *Saratoga* are compared in Table 3.

COMPARISON OF THEORY AND EXPERIMENT

Tables 2 and 3 summarize available experimental data in air and water respectively. It can be seen from Table 2 that the theory developed herein generally predicts a higher frequency in air than observed. This was to be expected because all idealizations made to facilitate analysis were in the direction of increased stiffness. It is unfortunate that the scant data available on vibration immersed should be for the one pair of struts for which theory predicted a lower frequency than observed. It is gratifying to note in Table 3, however, that the theoretical frequency in water differs from the observed by the same relative amount as did the frequency in air. This lends credence to the assumption of the cylinder whose diameter is equal to maximum dimension of the cross section. It is also interesting to note that for the first mode the mass of entrained water is slightly overestimated whereas for the second mode it is slightly underestimated.

It is extremely gratifying to see that the frequencies observed with the ship underway in free route, a realistic condition, agree even better with the theoretical frequencies than did those determined under the artificial condition of a ship in a flooded drydock.

GENERAL COMMENTS

The consideration of the strut system as a single arm fixed at one end and simply supported at the other, the design basis developed from the *Bennington* data, is conservative in that it predicts resonance at frequencies somewhat lower than observed. Its chief disadvantage lies in predicting different frequencies for the two arms, which fact is not confirmed by observation. On the other hand, the analysis developed herein is predicted on a single frequency per mode for the system as a whole. The solution given in this paper is somewhat more complicated than that previously used, but its application is equally simple if Figure 5 and Equation (8d) are used together.

The designer is interested in natural frequencies only when excitation exists. Careful orientation of the strut arms eliminates the possibility of flow excitation. Thus, the designer is faced with the problem of avoiding blade frequency resonance. If such a resonance cannot be avoided throughout the operating range, it should be accepted only at small fractions of rated power. That this is acceptable is verified by the extremely small amplitudes and stresses measured at resonances at the lower end of the operating range (2).

TABLE 3—*Comparison of Theoretical and Experimental Frequencies in Water for Saratoga*

Mode	L_2/L_1	Strut Section	f_a, cpm		Percent Dif.	f_w, cpm		Percent Dif.	f_w, cpm	Percent Dif.
			Theory	Exp.*		Theory	Exp.*		Exp.**	
1	0.853	EPH	842	890	− 5.39	647	690	−6.23	660	−1.97
2	0.853	EPH	1341	1500	−10.6	1031	1140	−9.57	1130	−9.52

* Vibration generator test in flooded drydock.
** Underway in free route.

CONCLUSIONS

1. Equation (5) predicts the natural frequencies in air of the shaft strut system with satisfactory engineering accuracy. The predicted frequencies are usually slightly higher than those observed.

2. Equation (8d) when used in conjunction with Figure 5 is a rapid way of predicting natural frequencies of the strut system.

3. For vibration normal to the plane of the strut arm, the mass of entrained water may be taken as that of a cylinder whose diameter is equal to the maximum dimension of the cross section.

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2. "Vibrations and Stresses Measured on Shaft Struts of USS *Saratoga* (CVA60)," by C. H. Kinsey, David Taylor Model Basin Report No. 1133, Washington, D.C., July 1957.
3. "Vibration Problems in Engineering," by S. Timoshenko, D. Van Nostrand Co., Inc., New York, N.Y., second edition, 1937.
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In a paper presented at the Symposium on Nuclear Powered Ships in Washington last July, Dr. Frederick De Hoffman discussed the gas cooled reactor for ship application. The paper cited three reasons for interest in this type reactor. First, the low atomic density of gases at temperatures and pressures in the range of interest means that a gaseous coolant will have little effect on the nuclear behavior of the reactor. Second, several gases under consideration as coolants are practically inert chemically, permitting a wider choice of possible structural materials in the reactor and coolant loop. Finally, no limit in temperature is imposed by the boiling point of a liquid coolant, allowing, in principle, higher reactor temperatures with accompanying higher thermal energies.

—from "Marine Engineering/Log," November 1957

New equipment has been installed at the experimental towing tank of the Stevens Institute of Technology which permits the testing of ship models at any heading to waves. The waves are generated on one side of the seventy-five foot square tank and travel across the tank to a metal beach on the opposite side, designed to minimize the wave reflection. The model is supported by a towing carriage which can be oriented to any direction with respect to the waves.

—from "Marine Engineering/Log," December 1957

"MECHANICAL ENGINEERING"

NEW MATERIALS

ACKNOWLEDGEMENT

This reprint is based on four papers presented at the Design Engineering Conference of The American Society of Mechanical Engineers in May 1957, and published in the August 1957 edition of "Mechanical Engineering." The authors are: Part I, Charles R. Simcoe of Battelle Memorial Institute; Part II, John H. Koenig and Edward J. Smoke of Rutgers University's School of Ceramics; Part III, Wyman Goss of General Electric Company; and Part IV, H. J. Reindl of General Motors Corporation.

I—Metallic Materials

AMONG THE METALS in quantity use today but commercially unapplied a decade ago are titanium, zirconium, and molybdenum. High-strength heat-treatable titanium-alloy sheet is of such potential that it is being investigated in the Department of Defense Titanium Sheet-Rolling Program.[1] Rhenium, with the second highest melting point of all metals is superior to tungsten and platinum-ruthenium for electrical contacts, and of particular use in electron-tube construction.

Developments in ferrous-base metals have been extensive, especially in ultra-high-strength steels, precipitation-hardenable stainless steels, high-manganese stainless steels, iron-aluminum-molybdenum alloys, and hot-die steels for constructional uses.

New processes developed include vacuum melting and vacuum casting to minimize the hydrogen content of iron and steel. Chem-milling permits the etching out of excess metal where machining would be difficult. Cladding and honeycomb construction permit the combination of metals or alloys to take advantage of their combined properties.

NEW FORMS WITH METALS

Honeycomb sandwich

Of the several ways of combining metals, the honeycomb sandwich is particularly attractive to the airframe industry.[2] In honeycomb-sandwich construction the cover plate can be made of aluminum, stainless steel, titanium, or other solid metals where strength or heat resistance is needed. These can be bonded to cores made of paper, reinforced plastics, aluminum, steel, or titanium by adhesives, soldering, brazing, or spot welding. A considerable amount of aluminum honeycomb structure has been used in the aircraft industry, but the present trend is toward stainless steel and titanium.

In addition to construction applications for exterior and interior curtain walls of buildings, honeycomb-sandwich structures could be used in appliances, cabinets, furniture, and rolling stock. Aluminum cover plates bonded to an aluminum core by adhesive bonding should be especially attractive.

Cladding

Another important method of combining metals is by cladding. Two or more materials can be bonded together, usually by rolling. While the method is not new, it is being used more extensively in such applications as atomic fuel element construction, and other use could be made to combine the desirable features of more than one metal or alloy. For nuclear fuel use, zirconium, aluminum, or other metals are bonded to a core of fissionable material to provide corrosion and erosion resistance. Such factors as hot and cold-rolling, compatibility between the core and clad materials, diffusion and phase relationships at the bond interfaces, and methods of testing the strength of bonds, have been studied extensively.

NEW METHODS

Chem-milling

A relatively new method of forming metals where unwanted material is etched out, rather than machined away, is Chem-milling.[3] It is being used in the aircraft industry, and can be applied to large structures and complex forms where machining would be impractical or impossible. Sheet structures containing integral ribs and stiffeners can be made from plate. Very close tolerance control is possible, especially with aluminum.

Vacuum casting

Vacuum casting has been applied to eliminate gases and volatile materials from metals and, particularly, to minimize the amount of hydrogen in iron and steel, which has been shown to be the cause of failure of large steel forgings, such as turbine rotors, and other steel parts which have been heat-treated to high strengths.

Many other metals and alloys are presently melted and cast, or cast only, in vacuum. Improvements have been noted in high-temperature properties, impact transition temperatures, and the ductility of materials processed in this manner.

Zone refining

A new process for purifying metals was developed at the Bell Telephone Laboratories as a result of a need for extremely pure material in transistors. The process is limited to small quantities of material at present, but is being developed for larger quantities. The method is called zone melting, and is an adaptation of fractional crystallization, long used for the purification of other materials. It is accomplished by moving a molten zone of metal along the length of a bar. Since impurities have a greater solubility in the liquid phase than in the solid phase, they tend to concentrate in this molten zone and are carried to one end of the bar. Eventually, when the process is repeated over and over, nearly all the impurities are swept out of the bulk of the bar. Almost inconceivable purities of 99.999999 per cent are common.

Roll forming

Metal fabrication by rolling metal powder directly into finished strip [4] was tried during World War II by the Germans. At least one company in this country is reclaiming copper scrap in powder form by rolling it into strip, and the process appears to be especially attractive for the fabrication of nuclear fuel elements. If the part is compacted cold, and never heat-treated, the very fine grains produce unique properties, and no preferred orientation is noted within the sheets. A metal strip can be clad on one or both sides by using it as the carrier of a chosen powder. A larger percentage of any scrap material reclaimed in powder form can be made into strip, rod, and wire, more cheaply than by conventional techniques.

TABLE 1—*Properties of New Titanium Alloys*

Alloys	Room-temperature properties in solution-treated condition: Ultimate tensile strength, psi	Tensile yield strength, psi	Elongation, per cent in 2 in.	Room-temperature properties in solution-treated and aged condition: Ultimate tensile strength, psi	Tensile yield strength, psi	Elongation, per cent in 2 in.
Ti-3Al-6Mo	135,000	—	15	180,000	160,000	7
Ti-4.5Al-3Mo-1V ...	150,000	125,000	15	170,000	150,000	10
Ti-2.5Al-16V	100,000	—	15	180,000	160,000	6

NEW METALS AND ALLOYS

Titanium

Measurable quantities of titanium, principally used in the manufacture of airframes and jet engines, have been produced within the last two or three years. Most promising alloy in the development stage is Ti-6Al-4V which may be the first truly all-purpose titanium alloy. Weldable in many applications, and superior for forging, it also shows promise as a fastener, and can be rolled into sheet with superior inherent strength and the added advantage of moderate heat-treatment response. Properties of new titanium alloys are shown in Table 1.

High-strength heat-treatable titanium alloy sheet is also under development. Among the compositions being studied are Ti-4.5Al-3Mo-1V, Ti-16V-2.5Al, and Ti-6Mo-3Al, Figure 1. These alloys have greater strength-weight ratios than ferrous-base alloys up to 400° F, and, in the case of Ti-16V-2.5Al, up to 700° F. If these alloys can be developed into useful aircraft constructional materials, their properties definitely ought to insure the future of titanium for some time to come.

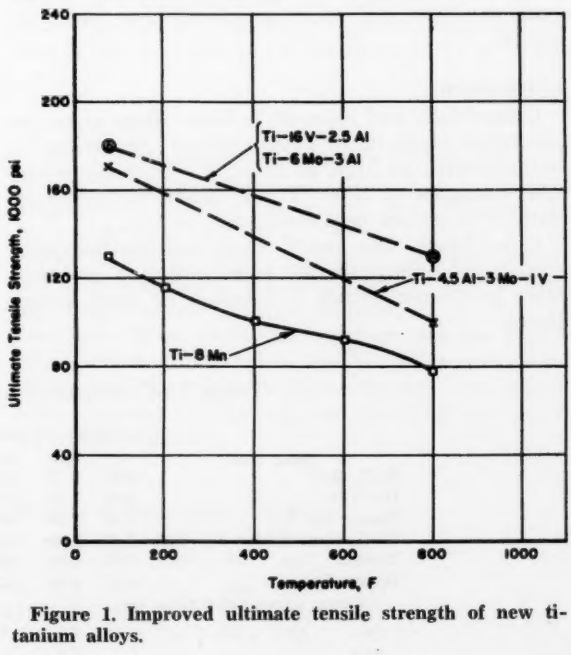

Figure 1. Improved ultimate tensile strength of new titanium alloys.

The next group of titanium alloys to be worked on should push ultimate tensile strengths above 200,000 psi at room temperature.

Beryllium

Beryllium, with a density ¼ that of steel and ½ that of aluminum, has considerable structural potential for aircraft.[5] It has a reported ultimate tensile strength of from 65,000 to 125,000 psi and a modulus of 44 million at room temperature. On a strength-weight basis, it may be superior to all present metals up to 1100° F. Unfortunately, the remarkable properties of this metal cannot be realized at present because it is extremely brittle at room temperature, and present costs are $100 per lb for powder. Toxicity, especially in powder form, is another disadvantage.

Chromium

New metals in the high-temperature group include chromium, columbium, and molybdenum. The greatest difficulty in using chromium is its lack of ductility, but swaged iodide chromium was made recently which shows excellent tensile ductility at room temperature.[6] The ductility is lost completely, however, if it has been recrystallized. On the other hand, chromium-base alloys with as much as 50 per cent iron or nickel show excellent tensile ductility after recrystallization. For example, a 50 per cent chromium and 50 per cent nickel alloy has an ultimate tensile strength of 154,000 psi, a yield strength of 123,000 psi, elongation of 25 per cent in ¾ in., and 57 per cent reduction in area. Elastic modulus is 32 million at room temperature and 22 million at 800° C.

Further advances in research should lead to the commercial application of chromium-base alloys, once ductility and other problems have been resolved.

Columbium

Columbium and columbium-base alloys show remarkable short-time stress-rupture properties at temperatures as high as 2200° F.[7] Short-time tensile strengths at 2200° F are 15,000 to 16,000 psi with 11 to 30 per cent elongation in 2 in.

Columbium, like most other high-melting-point metals, requires protection from oxidation, and tests were performed either in vacuum or inert atmosphere.

Molybdenum

Molybdenum, which has the greatest inherent strength to the highest temperatures, possesses two very important disadvantages—lack of room-temperature ductility, and volatile oxidation at high temperatures.[8] Research over the past 5 or 6 years has shown that the lack of room-temperature ductility is probably associated with a grain-boundary oxide. Research has shown that alloying will not sufficiently improve oxidation resistance; coatings must be developed for this purpose.

Recent developments indicate that the addition of 0.5 per cent titanium to molybdenum imparts a considerable increase in strength properties.[9] The 0.5 per cent titanium alloy has a short-time elevated-temperature strength at 1600° F which is equivalent to unalloyed molybdenum at room temperature. The stress to rupture in 100 hr, was increased by this alloy addition from 31,000 psi to 66,000 psi at 1600° F, from 22,000 to 53,000 psi at 1800° F, and from 13,000 to 43,000 psi at 2000° F.

Rhenium

One of the most important potential uses of rhenium is for construction material in electron tubes where residual water vapor reacts with tungsten to form tungsten oxide, and sets up a "water cycle" of oxidation and deposition. Rhenium resists water cycling, does not form carbide, and remains ductile after thermal cycling, being undamaged by fatigue or impact. In addition to the second highest melting point of all metals 5740° F, it has a Young's modulus of 67 million and an ultimate tensile strength of 170,000 psi.

Rhenium is a major alloying element in molybdenum which has practically no ductility at room temperature. It can be easily cold rolled 95 per cent with the addition of 35 per cent rhenium. Rhenium alloyed with tungsten can be worked at 800° to 1000° C, and this latter material may also be of interest in electron tubes.

DEVELOPMENT OF OLD METALS

Great strides have been made in the development of more common metals. Ultra-high-strength steels and precipitation-hardenable stainless steels are being developed as well as high-manganese stainless steels to replace high-nickel grades. Hot-die steels for constructional uses, especially in aircraft, and iron-aluminum-molybdenum alloys known as Thermenol are other developments.

TABLE 2—*Composition of Ultra-High-Strength Steels*

Steel type	Average composition, per cent							Tempering temperature, °F	Ultimate tensile strength, psi
	C	Mn	Si	Ni	Cr	Mo	V		
SAE 4340	0.40	0.75	a	1.83	0.80	0.25	—	450	270,000
Hy-Tuf	0.25	1.35	1.50	1.83	0.30	0.40	—	550	230,000
Super Hy-Tuf	0.40	1.30	2.30	—	1.40	0.35	0.20	550	290,000
Hi-Carbon Super Hy-Tuf	0.47	1.28	2.42	—	1.11	0.42	0.25	500	325,000
Tricent	0.43	0.80	1.60	1.83	0.85	0.38	0.08	500	300,000
Super Tricent	0.55	0.80	2.10	3.60	0.90	0.50	—	400	340,000

[a] Normal silicon 0.20-0.35 per cent.

TABLE 3—*Mechanical Properties of Ultra-High-Strength Steels*

Steel type	Tempering temperature, °F	Ultimate tensile strength, psi	Yield strength (0.2 per cent), psi	Elongation, per cent in 2 in.	Reduction of area, per cent	Charpy V-notch impact, ft-lb
SAE 4340	920	190,000	180,000	15	49	27
SAE 4340	450	270,000	212,000	10	35	19
Hy-Tuf	550	230,000	190,000	13	49	30
Super Hy-Tuf	550	290,000	241,000	10	35	14
Hi-Carbon Super Hy-Tuf	500	325,000	—	—	24	10
Tricent	500	300,000	242,000	8	23	18
Super Tricent	400	340,000	—	—	—	12

Ultra-high-strength steels

Strength has been increased in this group by increasing the resistance to tempering at any given tempering temperature, by addition of large amounts of silicon or variations in other alloying elements, such as carbon, manganese, nickel, chrome, molybdenum, and vanadium. The composition and properties of this group are shown in Tables 2 and 3.

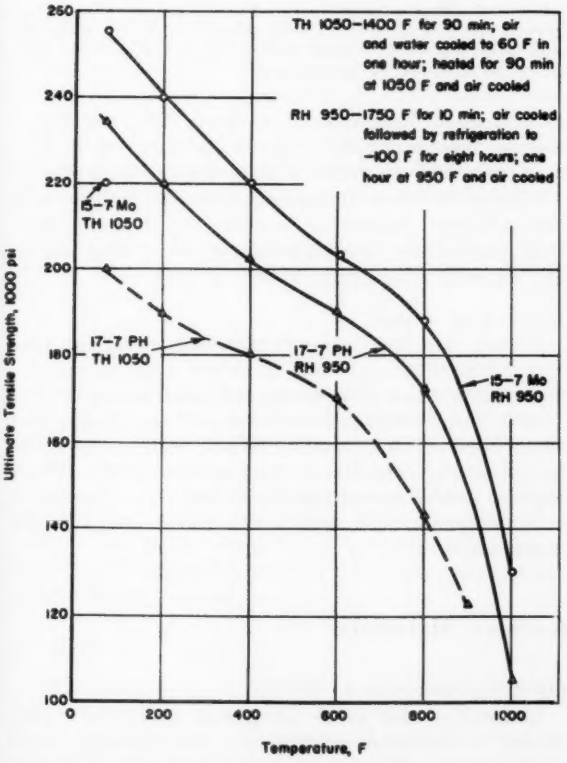

Figure 2. Ultimate tensile strength of new precipitation-hardenable steels.

Precipitation-hardenable stainless steels

Increased ultimate tensile and yield strengths have been achieved with heat-treatment of 17-7PH, designated Condition RH-950, which consists of heating at 1750° for 10 min. and air cooling.

The material is refrigerated at −100°F for 8 hr and then tempered at 950°F for 1 hour. This treatment produces ultimate tensile strengths of approximately 230,000 psi and yield strengths of 215,000 psi with 7 per cent elongation. This is an increase of approximately 38,000 psi in both the ultimate and yield strengths over the TH-1050 treatment, as shown in Figure 2.

A new precipitation-hardening alloy has been announced by Armco which is known as PH15-7Mo.[10] This alloy contains from 14 to 16 per cent chromium, 6.5 to 7.75 per cent nickel, 2.0 to 3.0 per cent molybdenum, and 0.75 to 1.50 per cent aluminum. It has exhibited ultimate tensile strengths of 220,000 and 240,000 psi, after the TH-1050 and RH-950 heat-treatments, respectively.

A bar, forging, billet, and plate alloy with slightly better tensile properties at both room temperature and elevated temperatures has been developed which is a companion to the AM-350 alloy, and is known as AM-355. The only apparent compositional change is a decrease in chromium from 17 to 15 per cent.

Thermenol.

The Thermenol series of alloys contains from 10 to 18 per cent aluminum and from 2 to 4 per cent molybdenum.[11] Some advantages of Thermenol are its low density (0.24 lb per cu in.) (Figure 3), its ability to retain room-temperature strength properties to temperatures as high as 1000°F, its excellent high-temperature oxidation resistance and corrosion resistance. Some of its disadvantages are low ductility at temperatures below 900°F, low heat conductivity, and very high work-hardening rate, which make forming, machining, and grinding operations somewhat difficult.

TABLE 4—*Nominal Composition of New Nickel-Base Alloys*

Alloy designation	Percentage										
	Ni	Cr	Fe	Co	Mo	Ti	Al	Cb	Mn	Si	C
Inconel 700	46.0	15.0	0.8	29.0	3.0	2.2	3.2	—	0.08	0.25	0.13
Inco 713	Bal.	13.0	1.0	—	4.5	0.6	6.0	2.25	0.15	0.4	0.12
Incoloy 901	40.0	13.0	Bal.	—	6.0	2.5	0.20	—	0.5	0.35	0.05
Hastelloy R-235	Bal.	15.5	10.0	2.5	5.5	2.5	2.0	—	—	—	0.16

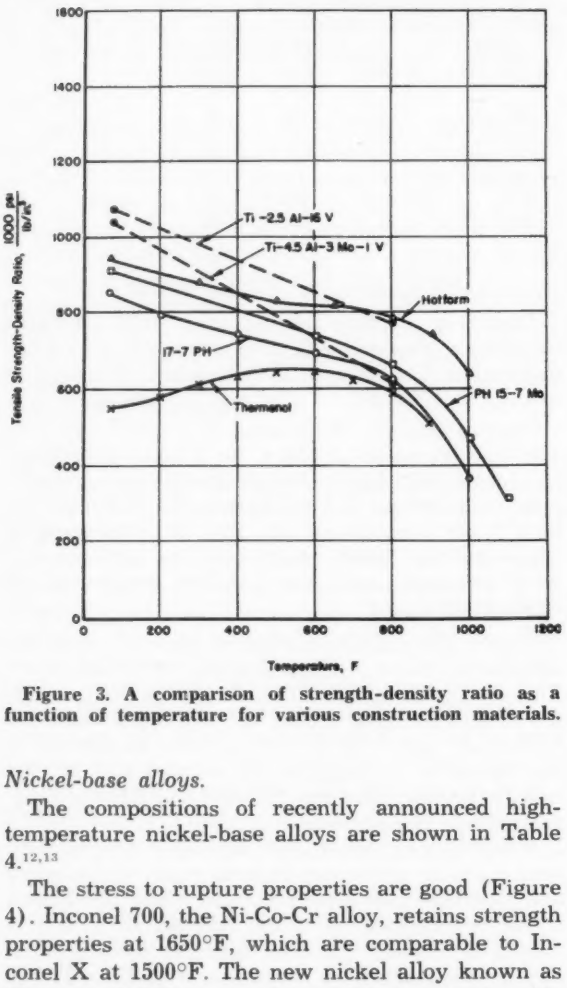

Figure 3. A comparison of strength-density ratio as a function of temperature for various construction materials.

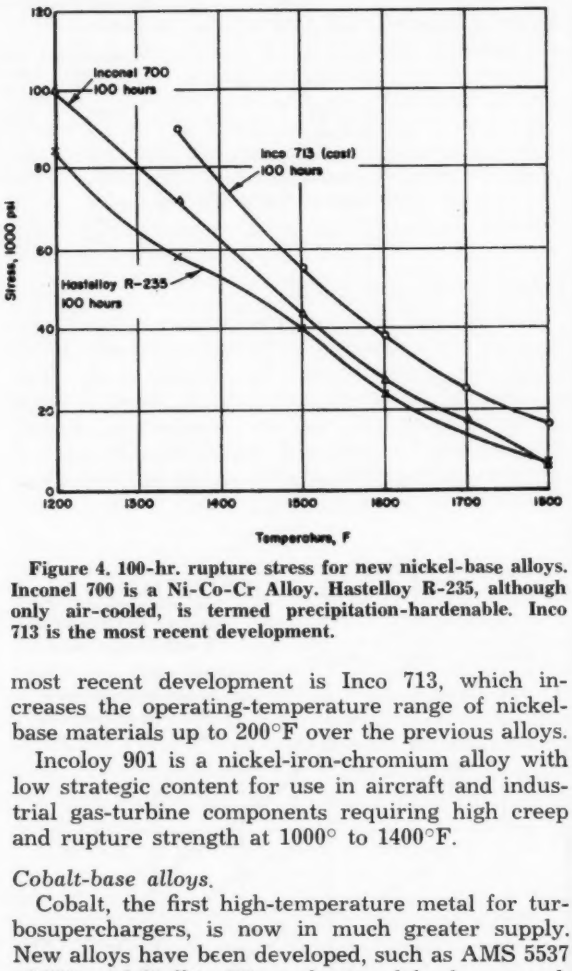

Figure 4. 100-hr. rupture stress for new nickel-base alloys. Inconel 700 is a Ni-Co-Cr Alloy. Hastelloy R-235, although only air-cooled, is termed precipitation-hardenable. Inco 713 is the most recent development.

Nickel-base alloys.

The compositions of recently announced high-temperature nickel-base alloys are shown in Table 4.[12,13]

The stress to rupture properties are good (Figure 4). Inconel 700, the Ni-Co-Cr alloy, retains strength properties at 1650°F, which are comparable to Inconel X at 1500°F. The new nickel alloy known as Hastelloy R-235 is termed a precipitation-hardenable alloy although only air cooling from 2150°F is required. Because the precipitating particles agglomerate slowly, there is little decrease in strength during long exposure at high temperatures. The most recent development is Inco 713, which increases the operating-temperature range of nickel-base materials up to 200°F over the previous alloys.

Incoloy 901 is a nickel-iron-chromium alloy with low strategic content for use in aircraft and industrial gas-turbine components requiring high creep and rupture strength at 1000° to 1400°F.

Cobalt-base alloys.

Cobalt, the first high-temperature metal for turbosuperchargers, is now in much greater supply. New alloys have been developed, such as AMS 5537 (L605, and Stellite 25) as sheet and for honeycomb structures, and a new alloy, WI-52, containing more tungsten and columbium than Stellite ×40. Cobalt imparts good thermal shock resistance to other high-temperature metals, and is especially useful in die materials.

II—Ceramics and Refractory Materials

GLASS

New developments in glass[14] include new processes and treatments, new types, and new uses for glass. Process and treatment developments include: centrifugal casting of bulbs; sintering after dry pressing, slip casting, or chemical treatment (foam glass, chemical forming, for example, photosensitive and devitrified glass); electrically conducting coatings and fused seals; reflection coatings, and electroluminescent glass. Currently, glass containers are being produced of lighter weight of uniform wall thickness and at higher speeds than ever before. Within limits this trend is expected to continue.

Optical glass.

Quantities and kinds of optical glass, mass-produced to extreme quality and homogeneity, have increased significantly. Selected lots are now spun into fibers, in the 25-micron thickness range, to serve as light pipes in bundles constituting the new field of fiber optics. Fiber optics will apply as image conveyances to medicine where crooked paths are necessary, as in gastroscopy, to coding, to image flattening, and similar applications. Optical glass fibers of 1 mm are being tested as dosimeters placed in real or phantom tissue in cancer research. Optical glass plates are being investigated as dosimeters in

food and drug sterilization research. In either case a stable and strong absorption change, induced by high energy radiation, represents the mechanism. New optical glasses for both lenses and windows have been developed for the infrared region (calcium aluminate, barium titanate, and high lead glasses).

Progress has also been noted in lighting glass, filters, and signalware, for example, ultraviolet and infrared-transmitting glass, incandescent lamp envelopes, diffusing and light-directing glassware, electroluminescent and explosion-proof light globes.

Improved acid-alkali resistant glass operates at higher temperatures and pressures, and has increased thermal shock resistance.

Surface treatments.

Silicones and other ultra-thin surface treatments, waxlike or organic in nature, have been applied to glass to greatly reduce scratching of containers during handling and processing. Silicone sprays have been recommended. The protective uses of ceramic coatings on glass containers to secure required protection against light—to prevent photochemical deterioration of pharmaceuticals, medicinals, and many other products—is of interest.[15] The proper thickness is applied to the outside surface of the container and permanently fused to the base container. These are essentially lead borosilicate glasses to which metallic oxides are added to develop particular colors. These durable ceramic coatings also provide for the control of the light-transmission characteristics.

Glass dispersion

A new glass dispersion provides a protective and lubricating coating during the forging of special alloy steels, titanium, and other metals. Applied to metals at room temperature, the glass fuses to the surface during the heating cycle and inhibits oxidation and surface contamination. A boron nitride dispersion has been found to be a good mold-release agent for metal molds and for automatic-glass-molding-machinery release.

Glass fibers

There has been increased production of glass fibers for many extended uses, such as household appliance insulation, noise control products, roofing products, pipe insulation, and insulation for air conditioners, including replacement air filters.[14] Fiberglass laminates of very high strength-to-weight ratio have increasing application for structural purposes, for example, glass-polyester parts being made for military applications (ducts and armor); automotive applications of glass-fiber products for instrument panel pads, sun visors, sound absorbing, and temperature-control insulation; and in electrical insulation primarily as replacement for phenolics.

A new fiber glass has been reported which, after being exposed for days at 2350°F, does not soften. This was developed for refractory applications. A micro-quartz lightweight insulation is being marketed which can be used at 2000°F and higher. It weighs but 3 lb per cu ft.

Glass fibers have been suggested as a paper additive to improve dimensional stability.[16] It would appear that the addition of relatively small amounts of glass fiber to pulp can result in improved dimensional stability in the sheet, without detracting from faster drying and reduced machine-width shrinkage.

A glass paper as a surface coating for plastics is being applied to increase surface abrasion resistance.

COATINGS

The trend in porcelain enamels, as noted in recent technical meetings, is toward lower temperature coatings (1000° to 1350°F) applied on lighter gage metals, and the use of thinner films. This reduces problems of distortion and warping of the metal. The new low-temperature enamels for steel and aluminum are made possible through the use of lead frits. Both steel and stainless foil 0.001 in. thick are now being enameled for high temperature service.

A new ceramic paint, now being used by the Army in mufflers and other high temperature applications up to 1400°F, contains a frit and a silicone.

In the field of higher temperature coatings, high temperature creep in alloys, for example, 80 per cent Ni, 20 per cent Cr, has been reduced under some conditions as much as 50 per cent at temperatures as high as 1975°F and loads up to 1200 psi. At 1800°F and 2200°F the creep decreased for a period of 20 to 30 hr after which it increased; this might have resulted from devitrification of the coating.

Molybdenum disilicide provides satisfactory oxidation resistance up to 3600°F as a coating on molybdeum.

Considerable progress has been made in flame-spraying ceramic coatings on different metals, for example, coatings of alumina, zircon, zirconia, and tungsten carbide, in thickness from 0.002 to 0.050 in. and finished to 0.5 micro-in. rms. Progress has been made in lowering porosity of such coatings to as low as 1 per cent. Illustrative uses include: protective coatings in jet, ramjet, and rocket engines; bearing surfaces; feed rolls; bus-bar insulation; circuit-breaker components; protection for valve plugs, pump shafts, and gas-turbine parts.

REFRACTORIES

Magnesite chrome basic refractory as a melt-cast product is being used in the steel industry to lower furnace-maintenance costs. Fire-brick applications

and high-temperature castable refractories for electric arc furnace roofs are also new.

Refractory castables are being used for jet aircraft and for missile-launching platforms; and silicon-carbide type refractories are playing vital roles in high temperature work.

A novel refractory development is a ceramic rope which resists heat up to 2300°F and is woven from a synthetic aluminosilicate fibrous material. This rope is extremely light in weight with a length of 30 ft at 0.5-in. diam weighing but one pound; this is 50 per cent lighter than an asbestos equivalent. It is used for expansion joints and high-temperature caulking.

CERMETS

Cermets are made by cold forming and sintering or hot pressing. The present well-known cermets include metal-bonded zirconium boride, nickel aluminide, and titanium carbide. In general, the borides are not as strong at room temperature as titanium carbide; however, at elevated temperatures they are much stronger.

In this field, a new cermet produced from silicon carbide and molybdenum provides for tremendous increase in strength with temperature.[17] At room temperature the transverse strength is 42,200 psi and increases to 71,900 psi at 1800°F. This latter value is among the highest attained in this temperature range.

For jet-engine applications a cermet based on chromium-molybdenum boride, and used up to 1800°F, exhibits better oxidation resistance and hot strength than titanium carbide, and has equivalent thermal shock resistance.

Tungsten and titanium carbides resist handling of sodium and sodium-potassium and other metals at 1050°F and above in pumps at 120 psi head over 2000 hours without wear.[18]

Another unusual property of a cermet, made from high purity tantalum carbide, results in the most uniform, concentrated light source yet developed. This material as the target is heated to a higher temperature than tungsten could withstand. The potential use for this new R-F lamp is in medical research, radar, air traffic control, printing, and projecting of motion pictures.

UNUSUAL CONSTRUCTIONS

The extremely high compressive strength of ceramics has led to its consideration in a number of constructions where its other unique properties, such as refractoriness, and hardness are also of practical interest. Prestressed ceramics are being studied for aircraft structures.[19]

Several types of ceramic honeycomb sandwich constructions, which can withstand temperatures up to 3000°F in repeated heatings, have been developed. These have compressive strengths up to 30,000 psi. The lower temperature variety is made of asbestos. The higher temperature type is made of long-fiber asbestos paper formed as hexagonal or square cores, dipped in alumina. These form the honeycomb on either surface of which a skin, made similarly, is applied. The whole is assembled and fired to 3000°F, burning out the paper and leaving the honeycomb alumina structure (total thickness 0.020 in.). The fired structure can be machined. Another sandwich construction reportedly used in a new high-speed jet plane involves the use of fiber glass as a honeycomb material between two layers of metal. This results in high resistance to buckling under temperatures and pressures encountered. A ceramic foam has also been developed which can be used continuously at 1600°F. This can be tamped or packed into relatively complex cavities. Some proposed uses include thermal and electrical insulation, core materials, fillers, and potting of electronic components.

STABILITY

The unique and stable properties of ceramics, particularly with respect to hardness and refractoriness, have provided many unique applications. Complete roller bearings, approximately 2½ in. in diam and 3 in. in length, including rollers and racers, have been made from high alumina ceramics. The integral parts must be machined to 0.0001 in. The coefficient of friction of alumina on alumina is low, and it is claimed that no lubricant is necessary.

Alumina ceramics with a hardness greater than tungsten carbide are used in making pumps for handling abrasive and corrosive materials. The plungers for these pumps have been made from ⅛ to 4 in. in diam and in lengths from 7 to 48 in.

Another potential application is for radomes, the dielectric windows, which house the radar equipment in the nose of a fast-flying plane or missile. Other types of materials are being considered for this purpose including devitrified glass, glass-bonded mica, and other polycrystalline ceramics. These and other type technical ceramics are now supplied as pistons and cylinders with maximum clearance of 0.0015 in.; parallel faces within 0.0005 in.; flatness within light bands; thickness 0.007 in. and up; tubes as small as 0.015 in. OD and 0.008 in. ID; threaded screws as small as 2-56; and drilled holes as small as 0.010 in.

A new high-temperature guard to protect metals from moisture and fumes utilizes ceramic-to-metal seals.

HARDNESS

The inflexibility, extreme abrasive resistance, and high strength of some ceramic materials allow their use as tools for high-speed machining of materials, especially metals, to close dimensional tolerance. The high rigidity prevents chattering and results in smoother cuts. Being nonmetallic, the ceramics do not weld to the metal being cut, and withstand more readily the high temperatures developed at the cutting edge without losing their properties; in fact, this extreme refractoriness obviates the need for coolants. These ceramics are non-absorbent, acid-resistant, and not subject to oxidation. Actual case histories of machining costs show reductions from 50 to 80 per cent through use of ceramic tools. Boron nitride, a new synthetic material, will scratch diamond and withstand temperatures greater than 3500°F, while diamond burns at approximately 1600°F.

III—Plastics and Rubbers

An example of the design and application possibilities of plastics is the modern automobile which contains 15 to 20 lb. There are about ten different plastic materials or copolymers used in the car's electrical system, fuel system, in the transmission, and in the body; in the running gear and engine, and in the numerous accessories.

Vinyls

A new development in vinyls is the spread coating of plastisols on steel.. The flexibility permits fabrication of the steel without cracking the coating. It is possible to stamp out auto fenders from this coated steel. The coated-steel price is estimated to be on the order of half that of laminated vinyl.

Vinyls are being applied to the plastic-pipe field and an estimated 6 million lb of resin are being consumed in this type of application. See Figures 5, 6 and 7.

Polystyrene

Polystyrene, the second largest in sales of plastic materials, sold close to 600 million lb last year, 400 million being in molding material. The largest single application is for refrigerator cabinet parts. These are made from standard styrene having impact strengths of 0.25 to 0.6 ft-lb or impact-grade styrene having impact strength of from 1.5 to 11 ft-lb. Styrene acrylonitrile copolymers, the higher impact materials, will find even more extensive use in this field.

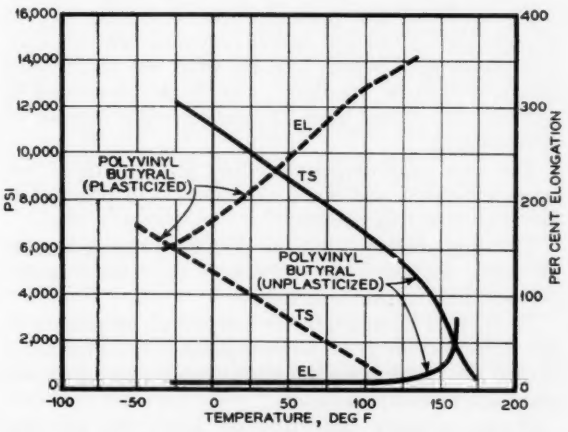

Figure 6. Tensile strength, elongation of polyvinyl butyral.

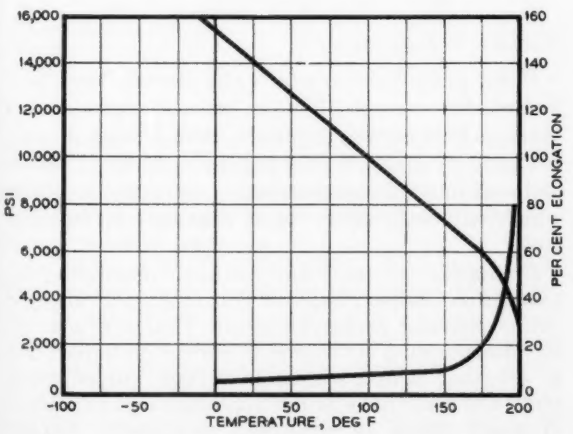

Figure 5. TS and elongation of unplasticized p olyvinyl formal.

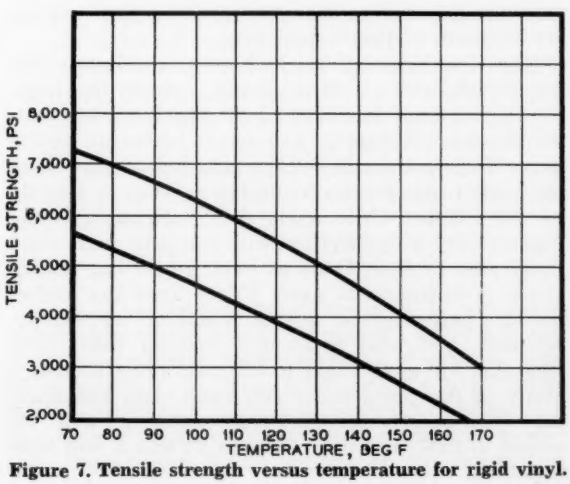

Figure 7. Tensile strength versus temperature for rigid vinyl.

TABLE 5—*Selected Properties of Polyethylene*

Density range	Low	Medium	High
Density, grams per mililiter	0.912 to 0.925	0.926 to 0.941	0.942 to 0.965
Heat resistance, max operating temp, °F	140° to 175°	160° to 200°	250°
Heat distortion 66 psi, °F	40° to 50° C	50° to 65° C	60° to 82° C
Izod, impact, ft-lb	16	16	0.5 to 5.5
Tensile, psi	1500 to 2400	1600 to 2500	2500 to 5000
Modulus, psi	14,000 to 38,000	35,000 to 90,000	85,000 to 160,000

Polyethylene

Polyethylene, a thermoplastic made by the polymerization of ethylene, is the fastest growing plastic at the present time and was third in sales last year with 500 million lb.

It is partly crystalline and partly amorphous with varying properties as the crystallinity is changed (Table 5). Manufacturing pressures and temperatures affect the crystallinity, and generally speaking, a high-pressure and high-temperature process is used to produce polymers of low to medium crystallinity while the low-pressure process is used to produce highly crystalline linear polymers. The crystalline phase is of higher density than the amorphous phase; therefore "medium" and "high," referring to density, are often used to describe the degree of crystallinity.

The new high-density product has gradually become available and some German-made product is being sold in this country.

This high-density material possesses higher tensile strength, higher heat resistance, the modulus increases, and impact decreases.

To further complicate the polyethylene picture is the announcement of polypropylene, a material of similar characteristics but with even greater stiffness and higher heat resistance.

Higher density polyethylene from the conventional high-pressure process has also been developed. This product, having a density of 0.93 to 0.94, will also have improved heat resistance, stiffness, clarity, and strength. These higher density products will make it possible to fabricate articles that require sterilization, and semi-flexibility.

High-density polyethylene has extremely interesting possibilities as wire coating, where the high-density material has better heat resistance and better abrasion resistance and much better oil resistance. This product is being evaluated in seat-cover applications, and rope made from fibers is already on the market. Once again it is believed that the high-density polyethylene will compete with rigid vinyl pipe in such fields as food processing, where steam sterilization is used. Films from the higher density polyethylene are outstanding for clarity, strength, and heat resistance, making them very desirable for application to the packaging industry. Many of the problems which have been bothering the high-density-polyethylene industry will be solved in 1957, and this is a product which will bear watching.

Considerable work is being done with polyethylene vacuum-forming sheet and when the present difficulties are ironed out, large new fields of polyethylene containers will be possible.

TABLE 6—*General Properties of Irradiated Polyethylene*

Specific gravity	0.92
Thermal conductivity, cal/sec/cm²/°C/cm	8.0×10^{-4}
Water absorption, per cent	<0.1
Melting point	None, behaves like an ideal rubber above 110° C
Coefficient of linear expansion, in/in/°C	2×10^{-4}
Environmental stress cracking	No failures after a year in glacial acetic acid or Igepal solution at room temperature, or after 2000 hr at 75° C
Chemical resistance	Excellent resistance to alkalies, to acids except nitric, and to most other common water-soluble chemicals
Solvent resistance	Good resistance to most organic solvents below 60° C. Above 60° C, is swollen by hydrocarbons, halogenated hydrocarbons, and aromatic solvents
Outdoor weathering	Should be protected from sun
Shelf life	Excellent
Thermal stability	Must be protected from oxidation

Nuclear Vulcanization

When polyethylene, which has already been fabricated, for example, film, or pipe, is exposed to a beam of high-energy electrons, cross linking or vulcanization occurs. A thermoplastic material which melts on heating thus becomes a thermoset material which will only soften upon heating but will not melt.

In addition to the form stability contributed by irradiation, better chemical resistance and slightly better physical properties result (Table 6 and 7). By incorporating stabilizers to permit prolonged use at elevated temperatures, irradiated polyethylene tapes and films have found application as insulation in many types of electrical equipment. Larger amounts of fillers, such as carbon black, can also be incorporated in polyethylene if the fabricated

TABLE 7—*Mechanical Properties of Irradiated Polyethylene*

		General purpose grade	Encapsulation grade
Gage, in.	—	0.005	0.004
Yield strength, psi[a]	23° C	1350-1750	>2000
	80° C	450- 600	> 500
	120° C	—	—
Tensile strength, psi[b]	23° C	1900-2500	>3000
	80° C	750- 900	>1200
	120° C	100- 200	> 150
Ultimate elongation, per cent[c]	23° C	300- 500	over 200
	80° C	300- 500	over 200
	120° C	200- 600	over 200
Shrinkage at lengthwise, per cent	150° C	25	40-50

[a,b,c] All tests run per ASTM standard D-882-54T.

TABLE 8—*Properties of Molded Phenolic Materials*

Shrinkage, mils per in.	4-5
Specific gravity	1.73
Water absorption, per cent in 24 hr.	0.2
Heat distortion, °F	325
Flexural, psi	8500
Modulus in flexural, psi	1.3×10^6
Tensile, psi	5000
Impact, notched Izod, ft-lb per in.	0.27
Compressive, psi	23,000

TABLE 9—*Selected Properties of Urea-Melamine Materials*

	Urea-cellulose filled	Melamine-cellulose filled	Melamine-fabric filled	Melamine-glass filled
Specific gravity	1.49	1.49	1.5	2.0
Izod impact, ft-lb	0.28	0.28	0.8	10.0
Water absorption, per cent in 24 hr	0.6	0.5	0.5	0.5
Arc resistance	130	130	120	180

TABLE 10—*Selected Properties of Nylon*

	Standard nylon	Polycaprolactam nylon
Impact, Izod, ft-lb per in. 77° F	0.9	1.2
Flexural strength, psi	14,600	15,500
Tensile strength, psi	11,500	9,600
Modulus in flexure, psi	410,000	385,000

parts made from this composition are subsequently cross linked. This has permitted the development of semiconducting cross-linked polyethylene tapes and films which augment the line of irradiated polyethylene insulating tapes.

In addition to all of the above properties, irradiated polyethylene containing the proper stabilizers will possess the following unique properties: Excellent resistance to thermal overloads, nonmelting character, elimination of the tendency to stress crack, stable electrical properties over a wide-temperature range, high resistance to surface arcing or tracking, ability to form tight, waterproof, and dustproof sheaths on taped objects.

Phenolics

Phenolics, the fourth largest plastic item in volume sales and largest of the thermosetting resins, sold about 450 million lb of products, 200 million as molding materials, and 75 million of resins for laminating. Other uses are for plywood binder, adhesives, resin binders for abrasives, brake bands, insulating wool, and surface coatings.

During the past year all suppliers of phenolic materials have continued their development of faster curing, easier molding material, and the technological competition between suppliers is tremendous. The use of rubber-modified phenolic molding materials (Table 8) continues to grow in applications where real abuse resistance is a necessity.

Heat resistance has been improved by 50°F, and it is now possible to find an improved arc resistance or tracking resistance in low-cost phenolic materials. The product is capable of being molded by transfer and compression techniques and its properties will allow for shorter tracking paths, thus resulting in smaller, more compact parts because less distance need be provided between electrical contacts. At the same time, low cost, good dimensional stability, appearance, and strength are retained. The product, being partially mineral filled, has good heat distortion, well over 300°F. This suggests the possible use in applications where high operating temperature precludes the use of many other molded plastics.

Glass-filled phenolics are one of the higher priced specialty items which have excellent mechanical characteristics. The automotive industry has also received a share of attention with respect to new development. Higher underhood temperatures and higher ignition voltages have led to the demand for materials which would withstand higher voltages at elevated temperatures.

Melamine materials

Melamine materials are formulated with numerous filler, alpha-cellulose, chopped-fabric filled, glass-filled, and mineral filled depending on the characteristics desired (Table 9). The type filler is primarily selected to produce certain mechanical properties that may be desired; however, care is exercised to select the filler that will allow for the retention of certain paramount properties inherent in the resin. For example, a highly arc-resistant, flame-resistant, and impact-resistant material would naturally be the glass-fiber-reinforced melamine-resin composition.

Nylon

A polycaprolactam-nylon material is somewhat softer than the conventional nylon (Table 10) and may be applicable where squeeze is desired, such as in washers, and its ease of molding larger parts with less difficulty indicates greater possibilities with this type of plastic in the future. It many find its way into the squeeze bottle application in competition

with polyethylene, and it is being looked at as a plastic-pipe material.

New extrusion grade Zytel No. 42 has a higher melt viscosity and is designed for extrusion. It is being used in automobile tubing application, the actuator rods for auto radio antennas, and bearings. Films from the new material can be laminated to paper foil and other films. Extruded window channels for autos are expected to be practical with the use of this new product. Its toughness and chemical resistance make it very desirable for aerosol containers. Bottles produced by the blow-molding technique are a promising application.

Resins

Delrin is a new resin based on formaldehyde which is expected to complement nylon. It has very low water absorption, exceptional light resistance, and distorts under a low load of 340°F. The developer has evaluation samples in process, but the commercial production is some time away as yet.

One of the most important developments in acrylics of the past year has been a new type of coating for automobiles which prevents color fading and reduces the need for polishing.

Du Pont is working with methacrylate monomer as a material for fibrous-glass reinforced plastic, in conjuction with dacron, dynel, and orlon fibers for use in post-forming.

Methylstyrene resins, available at about the same price as polystyrenes, but having higher heat resistance, have been introduced. Moldings of this material can be heated in boiling water with ultimate shrinkage of only 0.3 per cent.

Synthetic rubbers

Isocyanate-base polymers, Polyurethane-type rubbers, still of interest primarily in military designs where necessity outweighs cost, hold great promise for the time when fabricating techniques are improved and manufacturing costs are reduced. Such products possess tremendous abrasion resistance. The long-awaited automobile tire which will outlast the car is a possible application.

Hycar synthetic-rubber fuel lines are being applied in autos, running from the gasoline tank to the carburetor, made from a hose based on rubber, rather than conventional metal-fuel line. Some of the newer automobile manufacturers are planning to use a large tank made of Hycar as a hydraulic accumulator in their hydraulic system.

This accumulator is to supply fluid for hydraulic brakes and power steering in the event that the motor shuts off for any reason. Within the next five years, oil-resistant rubber may be used to manufacture fuel cells in autos the same way that these rubbers are now used to make fuel cells in aircraft.

Lexen polycarbonate resin is one of the latest materials.

The properties of plastics have made significant contributions to many industries important to all of us. Many design characteristics of today's familiar consumer and industrial products have been made possible by these special properties. The materials mentioned, together with those now in the test-tube stages, will emphasize the important trends in design, which are miniaturization, the wider use of color, and the importance of chemical properties.

IV—Coatings and Finishes

Coatings or finishes for engineering materials are used for sealing; to prevent corrosion; to improve electrical, thermal, frictional, abrasion, or wear characteristics; to provide increased strength; or promote better adhesion of other materials—in addition to their appearance value.

They have been divided for discussion purposes into three general classifications: organic coatings, metallic coatings, and conversion coatings.

ORGANIC COATINGS

Varnishes and enamels may be either air dryed or baked to produce the ultimate physical properties. For general discussion, enamels may be defined as pigmented varnishes. Some of the newer enamels or varnishes are the Epoxy, Hypalon, and Polyurethane types.

Epoxy type

The epoxy type has excellent chemical resistance, flexibility, impact, and abrasion resistance, as well as superior adhesion to all the commonly coated surfaces. They may be formulated to be resistant to most liquid and gaseous industrial chemicals, liquid foodstuffs, acid fumes and splashing, and other destructive agents. Strong mineral acids should be avoided.

They have the disadvantage of poor shelf life; and since most formulations include catalyst-type curing, it creates production problems and is unhandy.

Epoxy coatings are used for such things as collapsible tube finishes, drum linings, electrical insulation, furniture finishes, gas and oil pipe lines, paper, and other similar uses.

Hypalon

Hypalon is another relatively new material that may be formulated either flexible, resilient, abrasion resistant, or as a hard coating. It is a polymer prepared by the simultaneous chlorination and sulfination of polyethylene. These coatings have excellent resistance to sunlight, weather, heat, ozone, a wide range of industrial chemicals, and flexing even at low temperatures. They are inherently color-stable and produce attractively colored films.

They may be formulated by air dry or heat cure at elevated temperatures as desired. Shelf life in the can is fair.

Without modification films are elastic, clear, and

glossy but tend to be tacky and exhibit surface drag. This can be helped by blending with other compatible materials.

Hypalon is used extensively as a coating over rubber for protection from attack by ozone and the degrading effects of weather. Some such uses are mats, radiator hose, foam door strips, extruded window seals, boots, sporting goods, textiles, and glass fiber. When blended with polyethylene or epoxy resin, for example, the coatings have excellent abrasion resistance.

Polyurethane

Polyurethane coatings have many physical properties far superior to the standard finishing materials. These coatings are formed by reacting an isocyanate-type catalyst with a polyester resin, polyethers, polyalcohols, or prepolymers and catalysts.

They have good adhesive properties, excellent wear resistance, as well as humidity and weather resistance, and can be formulated to be anything from soft with high elastic properties, to hard with lower elastic properties. Polyurethane may be used clear or pigmented and may be baked or air dried.

Limited shelf life, tendency to discolor slightly on prolonged exposure, allergy hazard from some of the reacting agents are objections, as well as the necessity for mixing with a catalyst before application, and the necessity for moisture freeness to prevent foaming.

The two lacquers which have received most attention in new developments are the acrylic type and vinyl type.

Acrylic resins

Acrylic resins are waterwhite, having excellent transparency and resistance to discoloration as well as resistance to water, alcohol, alkalis, acids, mineral oils, vegetable oils, greases, chemical fumes, and relatively high resistance to burning, as well as having good gloss retention.

As an automobile finish with high metallic and pastel colors, acrylic resins retain high gloss for 18 months to 3 years without waxing, although the cost is high, and spotting is a problem. Chemical resistance and resistance to moisture are good at normal temperatures, suiting them to use for can and tank liners.

Vinyl lacquers

Vinyl lacquers have high chemical resistance, and are not attacked at normal temperatures by alkalies, mineral acids, alcohols, greases, oils, or aliphatic hydrocarbons. They have good resistance to moisture, high film strength, and good elasticity when formulated as such.

"Latex" paints

Water and styrene butadiene dispersion paints, known as latex types, are widely popular because of ease of application and other properties. They are most used for household decoration, although their properties suit them to wider applications.

Silicone primers

Water-soluble silicone primers are now available for industrial use which provide excellent water repellency for concrete, brick, stone, cinder block, bridges, and highways. These surfaces give longer life since subsequent penetration by water is greatly reduced and freezing damage is minimized.

Fluorocarbon dispersions

Fluorocarbon dispersions are available for coating a wide range of metals. Teflon, a polytetrafluoro ethylene material, which displays phenomenal antistick properties, is fused at approximately 750°F for maximum physical properties. Kel-F, a polychloro trifluoro ethylene material, also displays properties similar to Teflon, but to a lesser degree. It may be fused to approximately 650°F. Both materials must be handled with extreme care as both the material and curing fumes are toxic.

They are still quite expensive and require care and experience to obtain good adhesion to the base material. Typical applications are bearings, baking pans, bobbin guides, tank linings, snowplow blades.

Plastisols

Plastisols, which are mixtures of resins and plasticizers that can be molded, cast, or converted into continuous films by the application of heat, are becoming more and more prominent. If the mixtures contain volatile thinners also, they are known as Organisols. They are usually based on dispersions of polyvinyl chloride, and can be varied in thickness and flexibility. They must be fused at approximately 350°F to produce homogeneous films. Films up to 15 mils can be sprayed, and up to ¼ in. thick can be applied by dipping a hot, thick metal part. They are usually applied over a varnish-type primer if good adhesion is necessary.

Application methods

Electrostatic application of organic finishes has made great strides in producing better-appearing and performing finishes with less paint. The process is basically one of charging paint particles and attracting them to the article to be painted by grounding the article or oppositely charging it. Some electro-static processes deliver 95 to 100 per cent of the paint to the article to be painted and cover parts difficult to reach by other methods.

The Hot Spray process or application of coating materials such as lacquers, synthetic enamels, vinyls, and high-viscosity asphaltum mastic with heat has been developed in recent years to make it practical to take advantage of greater speed, economy, and efficiency of spraying. In this method, heat is used to reduce most materials to spraying viscosity without the use of large quantities of "thinners."

The Fluidized Bed Method, which produces coatings of 3 to 15 mils, is a process invented and pat-

ented in Germany and recently introduced into the United States. The process consists essentially of dipping a preheated article into a level bed of finely divided or powdered coating material which is suspended in a tank by an ascending current of gas or air. The article to be coated must be capable of being preheated without distortion or decomposition to a temperature above the melting point of the powder into which it is dipped. By proper selection of the coating material, a wide range of products may be coated, such as metals, ceramics, wood, or glass.

METALLIC COATINGS

Metallic coatings have also received considerable attention in recent development work on both old and new techniques.

High vacuum metallizing has opened new fields of metal-coating applications and replaced some electro-plating procedures. By this process, a thin metallic coating ordinarily a few millionths of an inch in thickness can be deposited on the surface of plastic, glass, metal, or painted surfaces.

This metallic coating is applied in a vacuum chamber at a pressure of approximately 1 micron or less, being heated and evaporated, then allowed to condense on all exposed surfaces. It is possible to rotate objects within the vacuum chamber by jigs and fixtures so that all surfaces are exposed.

While aluminum is the usual coating material, sometimes zinc, silver, gold, copper, nickel, tin, and many other metals as well as inorganic compounds may be applied.

The coating produced is an exact replica of the surface upon which it is formed. Therefore, to produce highly reflective bright coatings, it is necessary to start with bright surfaces.

Second surface coatings can be applied on the reverse side of clear plastics or glass, and the finish viewed through the material.

Conductive coatings

Electrically conductive coatings can be applied to nonconductive materials for many purposes. Some are lacquers containing high metallic contents of silver, copper, or aluminum. They may be applied by spray, dip, paint, or roll. Conductive coatings may also be applied by vacuum metallizing and by the chemical reduction of a metallic salt from solution similar to the silver nitrate method of mirroring.

Wear-resistant coatings

Tungsten carbide may be applied to the surface of a metal by a new process now being developed. This coating generally consists of almost-diamond-hard tungsten-carbide particles applied in a thin coating having excellent wear resistance and fairly good flexibility. The carbide is applied in the form of a powder, and application temperatures are claimed to be low enough to permit aluminum to be coated without distortion. Other details are not available. Typical applications are machine spindles, draw dies, plug gages, and burnishing broaches.

Process Developments

Much work has been done in producing nickel coatings by direct reduction of nickel salts from solution without the use of electric current. The process, particularly promising for special applications, is referred to as "Electroless Nickel." The thickness of coating, ranging from 0.50 mil to 10 mils or more, is dependent upon time immersion. The nickel plate may be heat treated to hardness levels in the neighborhood of 450 Vickers or better. These coatings may contain 5 to 7 per cent phosphorus, and may be applied to steel, aluminum, copper, nickel, and other base metals. The coatings are uniformly deposited on the base metal and are not subject to the throwing power characteristics of electroplating baths. Typical applications are valves, gears, tube interiors, tank interiors, pistons, threads, and bearings.

Hot-dip metal coatings of aluminum, obtained by immersing a metal part in a bath of molten aluminum, after previous fluxing to obtain adhesion, is receiving considerable attention for coating steel. They seem promising for general use, especially in industrial atmospheres, and for protecting steel from high-temperature oxidation. Hot-dip aluminum-coated-steel sheet, strip, and wire are commercially available.

A diffusion-type coating can be produced by heating a base metal, usually steel, while in intimate contact with another metal in powder, liquid, or gaseous form. This produces an alloy-rich surface layer. Chromized coatings of 4 to 8 mils on steel have corrosion resistance similar to that of high-chromium steel. Temperature resistance is even better than high-chromium steel. These coatings are used on valves, pumps, gages, tools, and parts requiring a combination of wear, corrosion resistance, and high-temperature resistance.

Sheets or plates of corrosion-resistant metals are sometimes welded or brazed to base metals where severe corrosion conditions make necessary a thicker and more economical coating. For some applications, stainless-steel clad or low-carbon sheets may be used in place of solid stainless. A great variety of clad-metal plate, sheet, strip, tubing, and wire are commercially available. Low-carbon steel sheets clad with textured vinyl and other types of organic materials are also commercially available.

Chromium plating

A new elecroplating procedure of applying chromium to a base metal referred to as "nonporous chromium" has recently been introduced. It is claimed to have increased corrosion protection over the standard chromium plate due to its nonporous nature. Coatings of 0.06 mil or better may be applied directly to a base metal, and it is claimed they offer

protection similar in some cases to that of the nickel-chromium or copper-nickel-chromium plates used.

Anodizing

The process of producing oxide films on aluminum is usually referred to as "anodizing." These films are produced by making aluminum or an aluminum alloy the anode in an electrolytic bath, usually of sulfuric acid, although many other electrolytes may be used. The coating formed will range in thickness from 0.05 mil to 3 mils and may provide wear resistance, corrosion protection, electrical insulation, base for adhesion of other materials, or a combination of these items.

Since the film formed varies from completely transparent to translucent, depending upon the alloy being anodized and the anodizing procedure used, the preliminary preparation given the aluminum to be anodized will affect the final appearance of the finished article.

Considerable effort has been expended on developing chemical brighteners which will produce a smooth, bright, lustrous finish on the aluminum, by immersion for 1 to 3 min in a chemical bath.

CONVERSION COATINGS

Anodic coatings

Excellent-colored anodic coatings may be obtained by immersing the anodized aluminum in a dye solution, or by chemical precipitation of mineral pigments in the pores of the oxide coating. These coloring materials can then be sealed into the coating by immersion in hot water, dilute nickel acetate, or some other sealing agent. The dyed coatings are satisfactory for indoor applications.

Colored anodized coatings for exterior exposure are now being used extensively where pigmenting of the coating is possible. In this case, iron oxide is precipitated into the pores of the oxide coating from a warm solution of ferric ammonium oxalate.

Extremely hard coatings of aluminum oxide can be produced on some alloys by special treatment in sulfuric acid electrolytes operated at low temperatures (20° to 35°F). Typical applications are pistons, valves, cams, brake disks, computing gears, impeller blades, and nozzles.

Phosphate coatings

Phosphate coatings applied by bringing the base metal into contact with aqueous solutions containing phosphate salts, phosphoric acid, and various reaction accelerators are used extensively for paint adhesion. They may also provide excellent corrosion protection when used in conjunction with oils and waxes. They may be applied to iron, steel, and zinc, and to a lesser extent to aluminum, cadmium, and tin.

Phosphate coatings are also receiving considerable attention as a basis for bonding other materials to iron, steel, zinc, and aluminum in particular. A complex but easily applied phosphate-oxide coating is available for tin. The invisible film is used on tinplate for atmospheric protection and to prevent unsightly blackening caused by sulfur-containing foods.

Protective films

Clear protective films produced on zinc, and zinc and cadmium-coated metals, are quite satisfactory for some applications. These films are usually applied in less than a minute from room-temperature acid-dichromate solutions. By immersion in organic dyes, some of these coatings can be converted into a variety of colors. Typical applications are automotive, aircraft, and ordnance parts.

Paint-base coatings

Chromate coatings developed for aluminum which can be applied in a few minutes from room temperature or warm solutions by immersion, spraying, brushing, or swabbing provide a paint-base and corrosion-protective coating at a cost much less than anodic treatments and can be applied to alloys which are difficult to anodize. The films are used for applications which require good corrosion-protection but little or no abrasion-resistance. They are excellent as a base for paint adhesion and find one of their greatest applications in this field.

Paint-base coatings for aluminum may also be produced by immersion for 10 to 20 minutes in a warm, alkaline-dichromate-carbonate solution. They give better corrosion protection when sealed by immersion in a boiling dilute dichromate solution.

Oxide coatings

Oxide coatings formed on steel at elevated temperatures, approximately 1000°F in the presence of steam, are extremely hard and abrasion-resistant. These oxide coatings are used on cutting tools such as drill bits made from high-speed-tool steel. The oxide coating provides less friction at the cutting face, minimizes welding of chips at the cutting edge, and gives extended life to each grinding of the drill bit.

There are undoubtedly many more recent developments in the field of finishing which deserve mention, and only the general details have been given on those discussed.

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A doubly-oriented magnetic sheet material which is easily magnetized in perpendicular directions has been developed. The General Electric Research Laboratory has perfected a process by which silicon-iron is given a cube texture which gives excellent magnetic properties for transformer core and electric motor applications. Singly oriented sheet material, previously developed for this use, reduced transformer core losses to about one-tenth those associated with unalloyed iron. The new "four-square" sheet material, as it is called, promises further improvements in efficiency.

—from "Mechanical Engineering," October 1957

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MARINE GAS TURBINE, FREE PISTON GAS TURBINE BIBLIOGRAPHY

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is Head Civilian of the Gas Turbine Branch of the Bureau of Ships. Holds degrees: BSEE electrical and BME in mechanical engineering. Is a registered professional engineer. Awarded eight patents in marine and other engineering fields. Active service in U.S. Navy as a Lieutenant Commander until 1949. Served as: chairman of Washington Section of ASME; president of Association of Senior Engineers; general chairman of National Gas Turbine Power Conference 1956; alternate chairman Marine Committee of Gas Turbine Power Division ASME; member of Council of American Society of Naval Engineers; member Navy Board of Civil Service Examiners; Now serving: member of Executive Committee of Gas Turbine Power Division ASME 1957-1962; alternate chairman of Marine Committee Gas Turbine Power Division; Chairman Program GTPD 1957-58; member General Technical Committee GTPD; Member of: American Society of Mechanical Engineers; Association of Senior Engineers; Society of Naval Architects and Marine Engineers; American Society of Naval Engineers. Has written a number of papers relating to gas turbines and other subjects in field of marine engineering. Several of these papers have appeared in the JOURNAL.

The marine use of gas turbines during the past few years has increased at a rapid rate. This accelerated use applies to both the gas turbine and the free piston-gas turbine engines. Improvements in materials, designs and component efficiencies have been primary contributing factors in the acceptance of these new prime movers. The realization of the advantages of the gas turbine by designers, naval architects, shipbuilders and marine engineers has also materially aided in the expansion of the field of application.

In 1947 the first gas turbine propelled ship went to sea. Since that time the Marine, including merchant and naval, installations have grown until in 1957 the total power, installed and building, exceeds 200,000 HP which is divided among more than 250 ships and boats.

During the past few years a number of papers have been presented to technical societies. Many articles have been publishd. A review of the papers and publications has been conducted and a bibliography prepared. The bibliography contains brief summaries of some 108 papers. These have been arranged by years, beginning with 1952 and extending through 1957. A subject index is included with the bibliography. The index contains approximately 450 subjects and has over 1050 references. Reference numbers have been assigned each article to permit ease of referencing in the index. For example under the subject "Fuel Treatment" reference 13-57 is listed. This is paper number 13 published in 1957.

It is hoped that this bibliography and index will be of interest and value to those who are concerned with design, selection, building, and operation of marine gas turbines.

The author expresses his appreciation to the Bureau of Ships, Department of the Navy, Department of Defense, for permission to publish this paper.

1957 PUBLICATIONS

1-57 "The Future for Marine Gas Turbines"—A. A. Hafer; Paper presented to the Southern California Section, The Society of Naval Architects and Marine Engineers, Jan. 17, 1957. Marine gas turbines for propulsion, in sizes above 3000 HP are discussed for merchant and naval use. Cycles include simple, regenerative, regenerative-intercooled, reheat-intercooled and regenerative-intercooled-reheat.

2-57 "Some Problems in Design and Use of Free Piston Gas-Generators on Board Ships"—A. Augustin-Normand, Jr. and M. E. Barthalon; The Shipbuilder and Marine Engine Builder, Jan. 1957, pp. 41-46. Material includes installation problems, propulsion, performance, starting, operation, fuel consumption and sea experience.

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7-57 "Liberty Ship *John Sergeant*: Variations on Aircraft Technology Make Maritime History"—General Electric Review, v. 60, n. 2, March, 1957, pp. 6-11. Installation of the gas turbine and early sea trials are discussed.

8-57 "A Review of British Naval Propulsion Engineering Progress in the Last Ten Years"—F. T. Mason (Twenty-First Parsons Memorial Lecture) Journal of The American Society of Naval Engineers, v. 69, n. 2, May 1957, pp. 255-261.

9-57 "The Trials and Maiden Voyage of the Gas Turbine Ship *John Sergeant*"—J. J. McMullen; Paper presented to The Society of Naval Architects and Marine Engineers, Spring Meeting, Long Beach, Calif., May 16-18, 1957. Sea trial and maiden voyage information is presented. This includes plant description, trial results, maneuvering, propeller performance, crew, turbine cleaning, fuel consumption and problems encountered.

10-57 "A Closed-Cycle Air Turbine for Naval Use"—W. Spillmann; Paper presented at The International Congress of Combustion Engines, 1957 Conference, Zurich, Switzerland, 17-22 June, 1957, 11 pp. Description of a 10,000 SHP closed cycle gas turbine propulsion plant, now under construction, is described.

11-57 "Une Turbine a gaz Prototype de 8000 ch et ses Applications a la Marine"—M. M. Aragou; Paper presented at The International Congress of Combustion Engines, 1957 Conference, Zurich, Switzerland, 17-22 June, 1957, 15 pp. A 6000 KW gas turbine and its potential for supplying peak power, with diesel engines as a base load, for use in a marine application is described.

12-57 "Gas Turbines as Prime Movers in Power Stations and Steelworks"—H. Pfenninger; Paper presented at The International Congress of Combustion Engines, 1957 Conference, Zurich, Switzerland, 17-22 June, 1957, 36 pp. Detailed analysis of maintenance, spare parts and personnel, and operating costs of a number of large gas turbine plants, up to 27,000 KW, are shown.

13-57 "Development of the Long-Life Marine Gas Turbine"—T. W. F. Brown; Paper presented at The International Congress of Combustion Engines, 1957 Conference, Zurich, Switzerland, 17-22 June, 1957, 37 pp. Gas Turbines for merchant ships are discussed. Material includes cycles, fuel problems, liquid cooling, components, reversing, and heat exchangers.

14-57 "Practical Experience With the Use of Residual Fuel Oils in Gas Turbines and the Influence of Additives Against Fuel Oil Ash Deposition and Corrosion"—W. Tipler; Paper presented at The International Congress of Combustion Engines, 1957 Conference, Zurich, Switzerland, 17-22 June, 1957, 31 pp. Experience in burning residual fuels, with various gas temperatures, and additives are discussed.

15-57 "YAG-37"—Information Release, Department of Defense, July 26, 1957. A Liberty ship, the *John L. Sullivan*, has been equipped with four 5,000 HP T-34 Pratt & Whitney turbo-prop engines. The installation, a total of 20,000 HP, will be operated at displacements of about 14,000 tons.

16-57 "Improving Gas Turbine Performance"—Part I-II, B. W. Martin; Part III, F. J. Bayley and N. Bell, American Society of Naval Engineers Journal, v. 69, n. 3, August 1957, pp. 537-550. These articles were first published in "Engineering." Part I—Thermal Efficiencies at High Temperatures. Part II—Effect of Intercooling on Efficiency. Part III—Heat Transfer Characteristics of a Liquid Metal in The Closed Thermosyphon.

17-57 "Shipboard Gas-Turbine Engine Tests"—P. W. Pichel, D. E. Blackwood and W. P. Henry, Jr.; Paper (No. 57-F-21) presented to The American Society of Mechanical Engineers, Fall Meeting, Hartford, Conn., Sept. 23-25, 1957. Results of an accelerated test of two gas turbine engines driving electric generators. Operating conditions, maintenance and inspection of the engines are described.

18-57 "Free-Piston Engines and Compressors"—J. A. Scanlan and B. H. Jennings; Paper (No. 56-A-23) presented to The American Society of Mechanical Engineers Annual Meeting, New York, N.Y., Nov. 25-30, 1957. A bibliography of free piston engines.

19-57 "Designing the Marine Gas Turbine"—F. R. Spurrier; Paper (No. 57-GTP-7) presented to The American Society of Mechanical Engineers, Gas Turbine Power Division Conference, Detroit, Mich., March 18-21, 1957. Design parameters for gas turbine engines as main propulsion for naval escorts.

20-57 "The Industrial and Marine Applications of Lycoming's Gas Turbines"—K. A. Austin; Paper presented to The American Society of Mechanical Engineers, Fall Meeting, Hartford, Conn., Sept. 22-25, 1957. The industrial and marine uses of the T-53 and T-55 gas turbine engines are discussed. The T-53 is being used to propel a naval boat.

21-57 "Gas Turbine Emergency Generator Set on *U. S. S. Gyatt*"—D. E. Blackwood; Bureau of Ships Journal, v. 8, n. 7, Nov. 1957. A 300 KW gas turbine generator set installed on the *U. S. S. Gyatt* is described.

22-57 "Design Considerations for Lightweight Gas Turbines with Regeneration"—G. L. Graves and D. Tempesco; American Society of Naval Engineers, Feb. 1957, pp 95-102. The effects on component efficiencies and regeneration effectiveness on plant performance.

1956 PUBLICATIONS

1-56 "Marine Proteus Engine"—B. G. Markham; Paper presented to the Sociey of Naval Architects and Marine Engineers, Chesapeake Section, Washington, D. C., Jan. 1956. A 3500 HP, free power turbine, developed for marine propulsion is presented. Engine was result of modification of aircraft engine.

2-56 "U. S. Navy's Gas Turbine Propelled Minesweeping Launches"—W. M. M. Fowden, Jr. and R. W. McAleer; Paper presented to the Society of Naval Architects and Marine Engineers, Chesapeake Section, Washington, D. C., Jan. 25, 1956. The propulsion plant of this 36-ft. minesweeping launch is a 220 HP gas turbine engine. A 100-KW electric generator is installed. This generator is driven by a second 220 HP gas turbine.

3-56 "Comparison of Total Weight and Bulk of In-Line Naval Gas Turbine Engine of Differing Degrees of Complexity"—D. F. Collinson and D. W. Thomas; International Shipbuilding Progress, v. 3, n. 17, Jan. 1956, pp. 25-36. Various gas turbine cycles, machinery arrangements, boost, cruise, fuel consumption, weight, bulk and deck openings are discussed.

4-56 "*Auris*—Sea-Going Experience over Four Years"—Oil Engine and Gas Turbine, v. 23, n. 272, Feb. 1956, pp. 380-382. Data include the sea experience of the *Auris* with the initial gas turbine installation. A 5500 HP engine will be installed with gear drive to the propeller.

5-56 "Gas Turbines in 1955"—The Engineer, Part 1—Jan. 13, 1956, pp. 59-62, Part II—Jan. 20, 1956, pp. 87-89. A review of industrial, aircraft and marine gas turbine developments.

6-56 "Development of High-Speed Sleeve Bearings for Solar 500-HP Gas Turbine Engine"—D. E. Blackwood and I. M. Swatman; Paper (No. 56-GTP-14) presented to the American Society of Mechanical Engineers, Gas Turbine Power Conference, Washington, D. C. April 16-18, 1956. Bearing developments for a 500 HP Marine gas turbine engine are described. Design problems, rig tests and engine tests to date are included.

7-56 "33,000 Hours on Marine Gas Turbines in Naval Service"—W. M. M. Fowden, Jr. and J. W. Sawyer; Paper (No. 56-GTP-7) presented at the American Society of Mechanical Engineers, Gas Turbine Power Conference, Washington, D. C., April 16-17, 1956. Operating experience on marine gas turbines in naval service.

8-56 "Design Considerations for Naval Gas Turbines"—G. L. Graves, Jr.; Paper (No. 56-GTP-1) presented at The American Society of Mechanical Engineers Gas Turbine Power Conference, Washington, D. C., April 16-18, 1956. Duty profile, operating requirements and basic parameters of engine design are discussed with respect to naval gas turbines.

9-56 "The Liquid Metal Fuel Reactor Closed-Cycle Gas Turbine Power Plant"—L. D. Stoughton and T. V. Sheehan; Paper (No. 56-GTP-12) presented at the American Society of Mechanical Engineers, Gas Turbine Power Conference, Washington, D. C. April 16-18, 1956. A nuclear power plant combining advantages of liquid metal fueled reactor with those of a closed cycle gas turbine.

10-56 "Operating Experience and Design Features of Closed Cycle Gas Turbine Power Plants"—Curt Keller; Paper (No. 56-GTP-15) presented at The American Society of Mechanical Engineers, Gas Turbine Power Division Conference, Washington, D. C. April 16-18, 1956. Work on closed cycle plants during the last five years is summarized.

11-56 "Internally Fired Semi-Closed Cycle Gas Turbine Plant for Naval Propulsion"—S. H. Dewitt and W. B. Boyum; Paper (No. 56-GTP-16) presented to The American Society of Mechanical Engineers, Gas Turbine Power Conference, Washington, D. C. April 16-18, 1956. This internally fired semi-closed cycle gas turbine plant was designed and manufactured for naval propulsion. Design and test data are presented.

12-56 "Reliability of *Auris* Gas Turbine"—Shipbuilding and Shipping Record, Apr. 1956, pp. 235-236. The

1200 HP gas turbine in the *Auris* has completed 17,510 hours operation at sea. This plant will soon be replaced with a 5500 HP geared gas turbine and hydraulic reverse gear.

13-56 "Controllable Pitch Propellers in Ship Propulsion"—R. F. Desel; Bureau of Ships Journal, v. 4, n. 12, Apr. 1956, pp. 2-6. Controllable pitch propellers are installed in a number of U. S. Naval ships with diesel and gas turbine propulsion.

14-56 "British Free-Piston Engine Development"—British Motor Ship, v. 37, n. 432, Mar., Apr., May, 1956, pp. 16-18. Results of trials of GS 34 gasifiers and study for a ship installation are given.

15-56 "Nuclear Power for Commercial Vessels"—K. Maddocks, The Institute of Marine Engineers Transactions, v. LXVIII, n. 5, May 1956, pp. 105-148. Survey of British and American unclassified material relating to nuclear power for marine propulsion. Five types of reactors are discussed. Gas cooled reactor is selected as most satisfactory for marine power plant. Discussions.

16-56 "The Future of The Marine Gas Turbine"—The Shipbuilder and Marine Engine Builder, v. 62, n. 564, May 1956, pp. 319-320. Marine gas turbines for propulsion are discussed.

17-56 "The Combustion Gas Turbine as Prime Mover for Ships"—A. A. Hafer; The Oil Forum, v. IX, n. 6, June 1956, pp. 229, 231. Advantages of gas turbine propulsion for ships are tabulated.

18-56 "Free Piston Gas Generators"—The Marine Engineer and Naval Architect, v. 79, n. 957, July, 1956, pp. 213-214. The free piston gas generators with gas turbines offer many attractive features for application in the marine field.

19-56 "Bristol Proteus Marine Gas Turbine"—The Marine Engineer and Naval Architect, July, 1956, pp. 222-224. The Bristol Proteus engine has been developed for marine service. This engine is rated at 3500 HP for thirty minutes and 2800 HP continuous.

20-56 "British Navy Makes Good Use of Gas Turbines"—L. Walter; Motorship, v. 41, n. 7, July, 1956, pp. 30-33. Naval applications of gas turbines for propulsion and auxiliary drives are considered.

21-56 "Exhaust-Stack Ejectors for Marine Gas Turbine Installations"—A. L. London; U. S. Navy contract N6onr-251, Task Order 6, Technical Report n. 26, July 1956. Marine power plant ventilation problems.

22-56 "Research at Pametrada"—The Oil Engine and Gas Turbine, v. XXIV, n. 276, Aug. 1956, p 164. Gas turbine development includes unit operating at 1200° C with temperature variation from combustion chamber plus 21° C to minus 33° C from mean. A 10,000 SHP marine gas turbine design has a specific fuel consumption of 0.39 lb. per shp-hr at 1204° C.

23-56 "Direct-Drive Gas-Turbine Unit for Tanker"—Engineering, Sept. 9, 1956, p 324. A new 5500 HP gas turbine is described for the tanker *Auris*.

24-56 "Lightweight 1130 HP Gas Turbine"—Marine Engineering, v. 61, n. 9, Sept. 1956, pp. 82-83. This lightweight split shaft engine has potential application for propulsion of small boats.

25-56 "A 40-Foot Personnel Boat with Gas Turbine Propulsion Engine Installation Features and Operating Experience"—P. G. Carlson, A. C. Ridland and D. E. Blackwood; Paper (No. 56-A-210) presented at the American Society of Mechanical Engineers Annual Meeting, New York, N. Y., Nov. 25-30, 1956. Installation and operating experience of the Solar T522J, 500 HP gas turbine in a U. S. Navy 40-ft personnel boat.

26-56 "Air and Gas Duct System for the Gas-Turbine Vessel *John Sergeant*"—W. A. Sherbrooke and H. Monroe, Jr.; Paper (No. 56-A-207) presented at The American Society of Mechanical Engineers Annual Meeting, New York, N. Y., Nov. 25-30, 1956. Ducts, dampers and expansion joints for the regenerative cycle of the ship are described.

27-56 "French Experience with Free-Piston Gasifiers"—M. Barthalon and H. Horgen; Paper (No. 56-A-209) presented to The American Society of Mechanical Engineers Annual Meeting, New York, N. Y., Nov. 25-30, 1956. The experience, over the past five years, accumulated by French engineers on operation and development of free piston gasifiers for use in marine and shore based installations is presented.

28-56 "Merchant Ship Power Plants of the Future"—J. J. McMullen, Paper presented at The Second Annual Symposium on Nuclear Gas Turbines, American Society of Mechanical Engineers, Washington, D. C., Dec. 4, 1956. Merchant ship power plants of the future are discussed in relation to size and application. Plants include free piston, diesel, steam turbine and gas turbine.

29-56 "Marine Gas Turbine Engine Data Book"—R. R. Peterson and D. E. Blackwood; Department of the Navy (United States) Bureau of Ships, Number NAVSHIPS-250-550-3, 15 Aug. 1956. A reference book written to present principal characteristics of gas turbine engines especially designed for or convertible to marine use. Forty engines are presented.

1955 PUBLICATIONS

1-55 "Gas Turbine Progress"—The Marine Engineer and Naval Architect, v. 78, n. 939, Feb. 1955, pp. 39-40. Merchant applications include the *Auris* and the Japanese training ship, *Hokuto Maru*, powered with a 500 HP gas turbine.

2-55 "Progress in Boeing's Small Gas Turbines"—W. B. Anderson; Proceedings of the American Power Conference, Seventeenth Annual Meeting, v. XVII, 1955, pp. 375-380. Developments in improving engine and component performance are traced over the past eight years.

Predicted performance indicates an engine with a 0.6 specific fuel consumption by 1958.

3-55 "Nuclear Propulsion of Merchant Ships—An Engineering Summary"—R. G. Folsom, H. A. Ohlgren, J. G. Lewis and M. E. Weech; Engineering Research Institute, Ann Arbor, Michigan, June 1955. Propulsion plants of merchant ships using nuclear reactors are presented.

4-55 "Fuels for U. S. Navy Gas Turbines"—H. F. King; Paper (No. 55-OGP-8) presented to the American Society of Mechanical Engineers, Oil and Gas Power Conference 1955. A program to investigate fuels for naval gas turbines.

5-55 "The Development of a 500 HP Multipurpose Gas Turbine Engine"—P. G. Carlson and I. N. Swatman; Paper (No. 55-S-36) presented to the American Society of Mechanical Engineers, Spring Meeting, 1955. The gas turbines, Solar Model T-400 J, T-520 J and T-522 J are described.

6-55 "Evaluation of a Naval Gas Turbine"—J. A. Culver and A. L. Wood; Paper presented at The American Society of Mechanical Engineers Diamond Jubilee Meeting, Baltimore, Md., April 18-22, 1955. Operating and maintenance experience with the Boeing 502-6, 160 HP, gas turbine driving auxiliary generators in 20,000 hours.

7-55 "Deicing by Gas Turbine Pump Rated"—D. E. Blackwood; Bureau of Ships Journal, v. 3, n. 11, Mar. 1955, pp. 7-9. Gas turbine exhaust gases have proved effective in melting ice formation on superstructure and machinery located on deck.

8-55 "Gas-Steam Turbines for Merchant Ships"—The Oil Engine and Gas Turbine, June, 1955, pp. 74-75. Reliability and other factors influencing gas turbine propulsion for naval and merchant applications are reviewed.

9-55 "Two Schemes for Merchant Ship Propulsion"—Oil Engine and Gas Turbine, v. 23, n. 264, June 1955, pp. 71-72. Information shown for machinery for two ships propelled by 3350 and 10,500 SHP plants.

10-55 "Marine Machinery of the Immediate Future From the Shipowner's Point of View"—J. E. Church; The Institute of Marine Engineers Transactions, v. LXVII, n. 7, July 1955, pp. 227-238. Daily operating costs of a 10,000-ton 14 knot cargo ship with the following propulsion plants: Diesel, diesel-steam, triple expansion diesel, gas turbine-steam, steam turbine and opposed piston.

11-55 "Liberty Ships with Free Piston Machinery"—British Motor-Ship, v. 36, n. 424, July 1955, pp. 154-155. Plant for a Liberty ship is presented, consists of four gas generators and one gas turbine that develops 4000 HP.

12-55 "H.M. Gunboat *Grey Goose*"—The Motorship, v. XXXVI, n. 425, Aug. 1955, pp. 188-189. This ship was placed in commission in 1955. The propulsion plant consists of two Rolls Royce gas turbine engines, RM-60, with full power rating at 5400 shp.

13-55 "1000-Hour Gas Turbine Test"—W. M. M. Fowden, Jr., Bureau of Ships Journal, v. 4, n. 6, Oct. 1955, pp. 19-22. Tests in the laboratory of a marine gas turbine are reviewed. Part failures are discussed. Inspection results reviewed.

14-55 "The Gas-Turbine Installation on the Liberty Ship *John Sergeant*"—J. J. McMullen; Paper (No. 4) presented to the Society of Naval Architects and Marine Engineers, Annual Meeting, New York, N. Y., Nov. 9-12, 1955. The first all-gas turbine installation in a merchant vessel is described. Material gives ship performance, estimated, gas turbine data and machinery arrangements.

15-55 "10,000-S.H.P. Gas Turbine Ship"—British Motorship, v. 36, n. 428, Nov. 1955, pp. 352-354. Pametrada design of two 5000 HP gas turbines for a merchant ship. Includes arrangement, astern power, fuel and comparison between diesel and steam.

16-55 "Nuclear Power Plants for Ship Propulsion Applications"—R. L. Witzke and S. A. Havershick; Electrical Engineering, American Institute of Electrical Engineers, Feb. 1955.

1954 PUBLICATIONS

1-54 "Nuclear Power Plants for Ship Propulsion"—F. E. Crever and T. Trocki; American Institute of Electrical Engineers General Meeting Conference Paper of Jan. 1954. Discussion of propulsion power plants for merchant ships involving nuclear reactors.

2-54 "High-Temperature Turbine Machinery"—T. W. F. Brown; British Motorship, v. 34, n. 407, Feb. 1954, pp. 498-499. The Pametrada 3500 HP marine gas turbine engine and its uses in work on controls, fuels, component efficiencies and corrosion is discussed.

3-54 "Continental Gas Turbines in 1953"—The Engineer, Feb. 19, 1954, pp. 272-273. The design and progress in construction of gas turbines by manufacturers in Europe is discussed.

4-54 "First Merchant Ship With Free Piston Gas Generators"—Shipbuilding and Shipping Record, v. 73, n. 10, Mar. 11, 1954, pp. 127-128, 131. Free piston propulsion plant being built for installation in coastal ship *Cantonac* is described.

5-54 "British Naval Gas Turbines"—G. F. A. Trewby; Paper presented at a joint meeting of Metropolitan New York Section of American Society of Mechanical Engineers and New York Metropolitan Section of Society of Naval Architects and Marine Engineers, April 27, 1954.

The eight gas turbine projects under Admiralty contract are reviewed. History, development, manufacture, design, operation and tests are presented.

6-54 "Designing Gears for Gas-Turbine Marine Applications"—R. J. Hoard and L. A. Acurso; Paper (No. 3) presented to the Society of Naval Architects and Marine Engineers, May 17-18, 1954. Design considerations for gas turbine gearing and applications in naval service are presented.

7-54 "British Lead With Navy Gas Turbine"—C. M. Jones; Marine Engineering, v. 59, n. 5, May 1954, pp. 54-61. The Rolls-Royce RM-60 Marine Gas turbines installed in *H.M.S. Grey Goose* are presented.

8-54 "200 HP Allen Gas Turbine"—Gas and Oil Power, v. 49, n. 587, May 1954, pp. 108-111. Development of a radial turbine for naval applications.

9-54 "Installation and Operating Experience with a Naval Gas Turbine"—J. O. White and J. S. Pasman; Paper (No. 54-SA-43) presented to the American Society of Mechanical Engineers Semi-Annual Conference, Pittsburgh, Pa., June 20-24, 1954—A 160-HP 220-lb. gas turbine engine installed in a standard landing craft, in three configurations is reviewed.

10-54 "Free-Piston Gas-Generator Turbine as Power Plant for Ship Propulsion"—F. A. I. Muntz and R. Huber; Institute of Marine Engineers Transactions, v. 66, n. 9, Sept. 1954, pp. 201-215. Information on design, operating cycle of GS-34 and CS-75.

11-54 "Fuel Systems and Controls for Marine Gas Turbines"—R. F. Darling; Proceedings of The Institution of Mechanical Engineers, v. 168, n. 5, 1954, pp. 159-165. The control system of the 3500 HP Pametrada marine gas turbine is discussed. Items include sprayers, control blocks, transmission, fuel system, reversing and governors.

12-54 "Recent Naval Steam Plant Designs"—C. H. Meigs; Paper presented at the Annual Meeting, Society of Naval Architects and Marine Engineers, Nov. 10-13, 1954, New York, N. Y. Data on steam propulsion plant, weights and performance. Gas turbine propulsion is also discussed.

13-54 "Main Propulsion Set for the Oil Tanker *Auris*" —B. E. G. Forsling; Proceedings of The Institution of Mechanical Engineers, v. 168, n. 5, 1954, pp. 166-189. The 1200 BHP gas turbine installed in the *Auris* operates on the simple open cycle with heat exchanger and independent power turbine. Engine design features, test experience and other data are presented. Discussions.

14-54 "Blackburn-Turbomeca Gas Turbine Engines"—Marine Engineer and Naval Architect, v. 77, n. 936, Nov. 1954, pp. 448-449. A number of small gas turbines having potential use for boat propulsion are presented.

15-54 "Gas Turbine Exhaust-Heat Recovery"—A. A. Hafer and W. B. Wilson; Paper presented at the American Society of Mechanical Engineers Annual Meeting, New York, N. Y., Dec. 1954. Methods of utilization of energy in gas turbine engine exhaust include: regeneration, exhaust, heat recovery boiler, and exhaust-fired cycle.

16-54 "Modified Residual Fuel for Gas Turbines"—B. O. Buckland and D. G. Sanders; Paper (No. 54-A-246) presented to American Society of Mechanical Engineers Annual Meeting 1954. Treatment of residual fuels to reduce sodium deposition and corrosion.

1953 PUBLICATIONS

1-53 "General Considerations in Naval Shipboard Power Machinery Development"—I. C. Jackson, Jr.; Journal of The American Society of Naval Engineers, v. 65, n. 2, May 1953, pp. 287-311. Various type propulsion plants are considered. These include: gas turbine and nuclear.

2-53 "The Development of High-Output Free Piston Gas Generators"—R. A. Lasley; Paper (No. 53-S-34) presented to the American Society of Mechanical Engineers Spring Meeting 1953. Development of free piston gas generator for naval propulsion.

3-53 "Closed-Cycle Air Turbine Installations for Marine Propulsion"—C. Keller and W. Spillman; Oil Engine and Gas Turbine, v. 21, n. 246, 247, Dec. 1953, pp. 317-319, Jan. 1954, pp. 355-358. Merchant marine plants utilizing closed-cycle gas turbines are presented along with fundamental data on the engines.

4-53 "6500 HP Naval Gas Turbine"—Engineer, v. 195, n. 5064, Feb. 13, 1953, pp. 238-239. The English Electric Co. 6500 HP gas turbine EL 60 A.

5-53 "Marine Gas Turbines in 1952"—Marine Engineer and Naval Architect, v. 76, n. 913, Feb. 1953, pp. 65-71. Naval and Merchant applications of gas turbines in the United States, France and England.

6-53 "Gas Turbines, with Particular Reference to Their Use for Marine Purposes"—Institute of Marine Engineers. Transactions, v. 65, n. 5, May 1953, pp. 1-4. Applications in naval and merchant ships.

7-53 "Further Research on Marine Gas Turbines"—Oil Engine and Gas Turbine, v. 21, n. 240, June 1953, pp. 66-68. The Pametrada test of a 3500 HP experimental gas turbine is described.

8-53 "R.M. 60 Marine Gas Turbine"—The Engineer, (British), Nov. 13, 1953. R.M. 60, 5400 HP, marine gas turbine engines, are to be installed in H.M.S. *Grey Goose*. Engine data, controls, compressors, intercoolers, reduction gearing, regenerators and performance are presented.

9-53 "The Gas Turbine as a Prime Mover on U. S. Naval Ships"—W. M. M. Fowden, Jr., R. R. Peterson and J. W. Sawyer; Paper (No. 53-A-233) presented at the Annual Meeting, American Society of Mechanical Engineers, New York, N. Y., Nov. 29-Dec. 4, 1953. Application and operating experience with gas turbines for propulsion and auxiliary use by the U. S. Navy.

10-53 "Operation of Marine Gas Turbine Under Sea Conditions"—J. Lamb and R. M. Duggan; (Paper presented to Institute of Marine Engineers) British Motor Ship, v. 34, n. 404, Nov. 1953, pp. 336-338. Two years performance of the 1200 HP gas turbine in the *Auris* is presented.

11-53 "Influence of Thermal Effects on Maneuverability of Marine Turbine Machinery"—B. J. Terrell; North East Coast Institution of Engineers and Shipbuilders Transactions, v. 70, pt. 2, Dec. 1953, pp. 93-120. Problems encountered in maneuvering turbines under high temperature conditions.

12-53 "Combination Propulsion Plants for Naval Vessels"—J. J. McMullen; Paper (No. 53-SA-71) presented to the American Society of Mechanical Engineers, Semi-Annual Meeting 1953. Combined gas turbine and steam turbine propulsion plants for naval vessels.

13-53 "The Free-Piston Type of Gas-Turbine Plant and Applications"—J. J. McMullen and R. P. Ramsey, Paper (No. 53-S-13) presented to the American Society of Mechanical Engineers Spring Meeting 1953. Possible applications of this type plant to ship propulsion.

14-53 "Atomic Propulsion with Special Reference to Marine Propulsion"—J. Cockcroft; Transactions Institute of Marine Engineers, v. 65, p. 105, 1953.

15-53 "Performance of Free-Piston Gas Generators"—J. J. McMullen; Paper (No. 53-S-18) presented to the American Society of Mechanical Engineers Spring Meeting 1953. High thermal efficiency of this plant makes it attractive for marine propulsion.

1952 PUBLICATIONS

1-52 "The Closed-Cycle Gas-Turbine-Power-Plant"—S. T. Robinson: Paper presented to the American Society of Mechanical Engineers Annual Meeting 1952. Development of the closed cycle plant with potential applications.

2-52 "Gas Turbine Alternator Propelling Machinery in Tanker *Auris*"—Engineering, v. 173, n. 4487, Jan. 25, 1952, pp. 119. Trials and data presented on the gas turbine propulsion plant.

3-52 "Marine Gas Turbines Afloat or Under Construction Today"—W. T. Sawyer, Marine Engineer and Naval Architect, v. 75, n. 899, Jan. 1952, pp. 9-14. Discussion of naval and merchant gas turbines in marine service or under construction.

4-52 "Gas Turbine Powered Tanker Completes First Voyage"—E. L. Lomax; World Petroleum, v. 23, n. 3, Mar. 1952, pp. 56-57. The tanker *Auris* completed first voyage. Performance data on gas turbine is discussed.

5-52 "A 1000-KW Gas Turbine-Alternator Set for The Admiralty"—Journal of the American Society of Naval Engineers, v. 64, n. 2, May 1952, pp. 370-371. Data presented on the gas turbine design and generator requirements.

6-52 "Gas Turbine Progress Report—Naval Vessels"—W. A. Dolan, Jr. and A. A. Hafer; Paper (No. 52-F-4C) presented at the Fall Meeting, American Society of Mechanical Engineers, Chicago, Ill., Sept. 7-11, 1952. Naval applications of gas turbines have many features common to merchant uses. This paper concerns those items that are unique to naval installations.

7-52 "Pametrada Marine Gas Turbine"—British Motorship, v. 33, n. 390, Sept. 1952, pp. 225-226. Test bed trial results of this 3500 HP marine gas turbine are presented.

8-52 "Gas Turbine Progress Report—Marine"—W. A. Dolan, Jr. and A. A. Hafer; Paper (No. 52-F-4A) presented at the Fall Meeting, American Society of Mechanical Engineers, Chicago, Ill., Sept. 7-11, 1952. Status of the marine gas turbine after the first 10 years of development and installation. First installations and their experiences are described.

9-52 "Marine Gas-Turbine from Viewpoint of Aeronautical Engineer"—A. Fletcher; Institute of Mechanical Engineers Proceedings, v. 166, n. 2, 1952, pp. 237-244. Application of aeronautical developments to marine gas turbine engines. Data include blade cooling and machinery layout.

10-52 "Gas Turbine Progress Report—Merchant Vessels"—W. A. Dolan, Jr. and A. A. Hafer; Paper (No. 52-F-4B) presented at the Fall Meeting, American Society of Mechanical Engineers, Chicago, Ill., Sept. 7-11, 1952. The gas turbine as a prime mover for merchant propulsion plants is discussed. Plants include the *Auris*.

11-52 "Gas Turbine Operating Experience in Tanker *Auris*"—Engineering, v. 174, n. 4529, Nov. 14, 1952, pp. 639-640. The first year's experience with this plant is described.

12-52 "Free Piston Gasifiers and Gas Turbines in French Coasters"—Gas and Oil Power, v. 47, n. 569, Dec. 1952, pp. 327-328. Propulsion plants of two vessels under construction are described.

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Boeing 502-6
Boeing 502-8c
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Bristol Proteus
British Thompson Huston
Clark Bros. 302
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Continental 141
English Electric EL60
English Electric EM27
General Electric 6700 HP
General Electric 7000 HP
General Electric 7600 HP
General Electric 8000 HP
General Electric 10600 HP
General Electric 12150 HP
General Motors GM-14
Lycoming LTCIB—1
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Simplified techniques for soldering aluminum, aluminum alloys, and galvanized metals have been developed by metallurgists at the Bell Telephone Laboratories. A zinc base alloy is used as a solder. The surface to be soldered is cleaned, after heating, by drawing the solder stick across the hot surface. This loosens and raises the oxide film which can then be brushed aside. The surfaces are then joined by adding the necessary additional solder. The technique is also effective for galvanized surfaces, the resulting joint being strong and stable. The success of the method hinges upon the high purity zinc base alloy used in the solder, from which all traces of lead, tin, bismuth and cadmium are excluded to prevent intergranular corrosion. A highly satisfactory bonding agent for joining polyethylene plastic products directly to rubber, brass, or brass-plated metals has also been developed at the Bell Laboratories. This is accomplished by use of a liquid polybutadiene product which produces a cemented joint having a peel strength of 100 psi and a tensile strength of 1000 psi.

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BOOK REVIEWS & NOTICES

CAVITATION IN HYDRODYNAMICS

Published in 1957 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, New York
6 Sections 22 Papers 465 Pages
$15.00

Reviewed by
Robert Taggart
Director, Experimental Test Division
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The first International Symposium on Cavitation in Hydrodynamics was held at the National Physical Laboratory, Teddington, England in September 1955. This Symposium was attended by some 140 delegates from 15 countries. The 22 papers presented during the six sessions and the discussions which followed are compiled in book form in *Cavitation in Hydrodynamics.*

As in any compilation of a series of papers which are related only in a general way, the book is lacking in continuity. For an inexperienced student or casual reader the background information necessary for a complete understanding of the subject is missing. However, this compilation is valuable in that it presents the state of knowledge in hydrodynamic cavitation at the time the Symposium was held.

The first session of the Symposium consisted of a review of progress in cavitation research by Phillip Eisenberg of the Office of Naval Research. In this review Mr. Eisenberg summarized the many facets of the cavitation problem, critically analyzed the state of knowledge, and pointed out the areas in which further research is needed.

The second session was devoted to the factors governing the inception of cavitation. E. E. Williams and P. McNulty of the Mechanical Engineering Research Laboratory, East Kilbride described a method of acoustically detecting incipient cavitation while varying the dissolved gas content, the velocity of the liquid, and the dissolved sodium nitrite content. G. Ziegler of the Technical University in Graz, Austria showed that pure water can take on high tensile stresses under certain working conditions without inception of cavitation. J. W. Daily and V. E. Johnson of the Hydrodynamics Laboratory, Massachusetts Institute of Technology described a series of experiments investigating the interrelation of the stability of small gas bubbles, their size and space distribution, and the velocity and pressure distribution in the turbulent boundary layer.

Messrs. Davies, Trevena, Rees, and Lewis of the University College of Wales, Aberystwyth further discussed the tensile strength of liquids under dynamic stress. Exact experimental values for distilled water contained within steel boundaries were given. Murray Strasberg of the David Taylor Model Basin then described the results of experiments he has conducted on the inception of cavitation in water containing undissolved air cavities. The ultrasonic experimental apparatus used was shown to be effective in demonstrating two fundamentally distinct forms of cavitation.

Experiment Techniques was the subject of the third session. Instrumentation for measuring fluctuating forces, pressure intensities and velocities was described by D. W. Appel of the Iowa Institute of Hydraulic Research, State University of Iowa. A. T. Ellis of California Institute of Technology described a high-speed photographic system used in the study of cavitation bubble collapse showing a series of interesting photographs of this phenomenon as well as photoelastic pictures of acoustic cavitation bubbles and the accompanying strain waves. The instrumentation for the Admiralty Research Laboratory Water Tunnel and Rotating Beam Channel was then described by H. Ritter of that establishment, and Messrs. Straub, Ripken and Olsen depicted the recirculating model water tunnel at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

The fourth session covered scale effect factors in cavitation. A general discussion on the subject as

related to water turbines was given by H. Gerber of the Technical University, Zurich, followed by a discussion of air entrainment at the rear of a steady cavity by R. N. Cox and W. A. Clayden of the Armament Research and Development Establishment, Fort Halstead. A. Silverleaf of the National Physical Laboratory then reported on the preliminary cavitation results obtained from a geometrically similar series of model propellers ranging from 6 to 12 inches in diameter. A series of experiments involving the observation and photographing of cavitation phenomena on the propellers and shaft struts of fast patrol boats and destroyers were next described by A. F. Weeks of the Admiralty Experiment Works, Haslar.

In the fifth session the effects of cavitation on hydrodynamic performance were discussed. The forces acting on hydrofoils under both cavitating and noncavitating flow were outlined by M. S. Plesset and B. R. Parkin of the California Institute of Technology. Marshall P. Tulin of the Office of Naval Research then delineated the problem of predicting the forces on practical bodies operating at low cavitation numbers, and F. Numachi of Tohoku University, Japan talked about the effect of static pressure differences on the cavitation characteristics of hydrofoil profiles.

The damage to underwater solids caused by cavitation was discussed at the sixth and final session. G. T. Callis of the Manganese Bronze and Brass Co., Ltd. reviewed the various explanations of the damage associated with cavitation. He suggested that cavitation damage is identical with impingement attack and that turbulence in the cavitating region is a major factor. Fixed type cavitation and its damage potential were then covered by Professor Robert T. Knapp of the California Institute of Technology followed by a description of experimental results in cavitation erosion by R. E. H. Rasmussen of the Technical University of Denmark. W. H. Wheeler of the Mechanical Engineering Research Laboratory, East Kilbride went into the details of the participation of the liquid and metal surfaces in cavitation erosion. Received too late for the session but included in the book was a paper by K. K. Shalnev of the Academy of Sciences, U.S.S.R. on an experimental study of the intensity of erosion due to cavitation.

An additional informal session was held on the subject of ultrasonic cavitation. The results of the discussions during this session are summarized in an appendix to the book.

The value of this publication is marred somewhat by the photo-offset form of reproduction which has been employed. Many of the photographs contained therein which were excellent originals lack clarity and detail. In addition, no attempt has been made to standardize the format of illustrations, graphs, or symbols which tends to make reading difficult.

In spite of these limitations, *Cavitation in Hydrodynamics* sets forth the state of knowledge in the field as expressed by a group of recognized experts representing countries throughout the world. It is probably the best available published summary on the subject and is recommended as an authoritative reference.

MARINE ELECTRICAL PRACTICE

By G. O. Watson, with Chapters by
R. A. Harvey, R. V. Mills, and H. R. Ruff

Published in 1957 by
Philosophical Library, Inc.,
15 East 40th Street, New York 16, N.Y.

182 Illustrations.
325 Pages. $12.00

Reviewed by Thomas E. Broderick,
Electrical Engineer with Department of the Navy,
Bureau of Ships

(G. O. Watson was a principal electrical engineer surveyor with Lloyd's Register of Shipping, and drafted Lloyd's First Rules for Electrical Propulsion of Ships. He is chairman of the International Electrotechnical Commission's Technical Committee on Electrical Installations in Ships and of the Institution of Electrical Engineers' Committee on Regulations for Electrical Equipment of Ships.)

It is a rare author who can cover A.C. and D.C. theory, equipment and distribution in ships without being wordy and overly technical. Mr. Watson is this rare author who not only accomplishes the above but also enriches the text with hints on safety precautions to be included in the design of a ship's electrical systems.

The book covers everything electrical on a ship except interior communication, electronic and alarm systems. The descriptions are based on British practice, but the underlying principles apply equally to that of other countries.

The author starts with the premise that there are two principal considerations in the selection and in-

stallation of marine electrical equipment: first, outstanding reliability and freedom from breakdown for those services essential to navigation and propulsion, and second, freedom from fire risks. He then describes the choice and installation of the individual components, beginning with the generators and going through the distribution to the individual motors and other electrical equipment.

Mr. Watson in his writing seems to favor the use of D.C. distribution for the ship's electrical system, but this does not keep him from covering the A.C. system. The comprehensive chapters on A.C. generators and switchgear are possibly the best presentation available on this subject, since these chapters stress voltage regulation and voltage transient problems and means to correct them. To do this he describes examples of the latest types of self regulating generators and voltage regulators, giving their construction and theory of operation. He also takes up the popular controversy of the grounded versus the non-grounded neutral three-phase system. Stating that it is not his purpose to enter into the pros and cons of such a system, the author proceeds to give a very good example of why the non-grounded neutral system is preferable. His argument is based on the fact that when two generators are operating in parallel with their neutrals grounded, any inequality of the third harmonic E.M.F.'s will produce a wattless circulating current. Because the third harmonic currents do not produce armature reaction, the current will be limited only by the leakage reactance and not by the synchronous reactance. Therefore, the third harmonic circulating current can be large, and when added to the load current, increases the stator losses, resulting in extra heating.

The author's treatment of the D.C. system is all inclusive, covering parallel operation of generators having different sizes and characteristics, three-wire systems using three-wire generators or rotary balances, and a most informative discussion on the protection devices for the D.C. system, which includes the complex subject of discrimination (selective tripping).

The importance of ship's steering is brought out by the writer in a chapter dealing with the electrical aspects of steering gear. He explains the two main types of gears, electro-hydraulic and all electric. Since manufacturers of all-electric steering gear use different circuits and principles in their design, it is not possible to give a typical example. Therefore, he describes the operation and theory of several leading types of gears including Ward Leonard and Sperry.

Tanker electrical systems have special requirements. In a separate discussion he deals with the particular rules which apply to these ships. He stresses the fact that with the exception of ground indicating devices, no part of the distribution system may be permanently grounded, and also gives special treatment to the main principles governing the construction of flameproof enclosures.

Mr. Robert H. Harvey has written the chapter on storage batteries. A wealth of knowledge on batteries is included in this chapter which deals with every aspect of battery installation, from choosing the right type down to first aid required to neutralize sulphuric acid burns.

Information on lighting installation has been written by Messrs. H. R. Ruff and R. V. Mills. They describe the different types of lighting equipment and refer to handbooks for lighting level requirements for spaces.

The last three chapters of the book cover graphical symbols, a list of organizations concerned with shipping and shipbuilding, a list of regulations affecting electrical installations, and useful information such as abbreviations, formulae and tables.

Seagoing engineers and electricians as well as engineers employed in the design, installation and maintenance of ship electrical systems will all find this book loaded with good basic marine engineering principles and worthy of their study.

BOOK NOTICE

MARINE NEWS DIRECTORY

Thirty-third Annual Edition, 1957-1958
Published in 1957 by
The New York Marine News Co., Inc.
26 Water Street, New York 4, N.Y.
568 pages $25.00

This directory is divided into the following sections:

1. American and Canadian Shipbuilding and Repair Yards.
2. American and Canadian Steamship and Waterway Lines.
3. American and Foreign Tankship Owners and Operators.
4. American and Canadian Dredging Companies.
5. Naval Architects, Marine Engineers, Consulting Engineers, Surveyors and Chief Draftsmen.
6. Air Cargo Firm List (new with this edition).
7. Port Section.
8. American Maritime Associations.
9. Naval Supplement, listing key personnel in various United States Government agencies.

INDUSTRIAL ELECTRONICS HANDBOOK

By R. Kretzmann

Second Edition, Published in 1957
by Philosophical Library, Inc.
15 East 40th Street, New York, N.Y.
298 pages $12.00

This book is intended to aid technicians engaged in the supervision or maintenance of industrial equipment, and industrial engineers who desire to acquaint themselves with the possibilities of electronic control and the methods of application. Part I deals with the principles and properties of the various types of electronic tubes. In Part II separate chapters are devoted to each of the main types of application, namely electronic relays, counting circuits, timers, rectifier circuits, electronic dimming of lights, speed and temperature control, control of resistance welding, motor control, high-frequency inductive heating of metals and high-frequency capacitive heating of dielectric materials.

INDUSTRIAL ELECTRONICS CIRCUITS

By R. Kretzmann

Published in 1957 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, N.Y.
194 pages $10.00

This is a sequel to "Industrial Electronics Handbook" by the same author. It deals with the circuity of industrial electronics apparatus, and includes nearly 200 circuits. The functions of the various circuit elements are described, and comprehensive information is also supplied on the actual component values. Included are photoelectrically controlled apparatus, counting circuits, stabilizing circuits, contact and control devices, oscillator and amplifier circuits, and rectifier and motor control circuits.

ROCKET

By Air Chief Marshal Sir Philip Joubert de la Ferté

Published in 1957 by
Philosophical Library, Inc.
15 East 40th St., New York 16, N.Y.
185 pages $6.00

This book is a little afield from naval engineering but relates to a subject which holds a place of great prominence in the contemporary press.

The author starts with a short historical account of the evolution of rockets: The World War II German efforts are described in length. This leaves the impression that only because of their own mistakes did Hitler fail to win the war against England by use of the V-1 buzz bombs and the V-2 rockets.

He describes how the British effort, coupled with German mistakes defeated the rocket and concludes with some discussion of future possibilities.

THE BRIDGE AT REMAGEN

By Ken Hechler

Published by
Ballantine Books,
101 Fifth Ave., New York 3, N.Y.
Paperbound edition 50c
Hardbound edition $4.50

In no sense an engineering book but one of historical military interest. The story of the unexpected good fortune of the U.S. Army in capturing a usable bridge across the Rhine may be generally known.

How it happened and what was done and by whom could make a routine document. Ken Hechler has set it out in a most fascinating manner. Few books have held the reader's attention as this one did this reviewer.—One of those rare books which has to be read through before it can be laid aside.

PANZER LEADER
By Heinz Guderian
Published by
Ballantine Books,
101 Fifth Ave., New York 3, N.Y.
Paperbound edition 50c (abridged)
Hardbound edition available from E. P. Dutton
$10.00

This is a second paperbound book which has nothing specifically to do with engineering. It is written by the one man who was closer to the development of tanks and their use in warfare than any other in the German army, possibly in any army. Well written in full detail, the story of General Guderian's career contains much information to explain the rise and fall of Nazism.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

It is a great pleasure to announce the addition of the following members since the pubication of the November, 1957 JOURNAL:

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Streeter, K. V., Civil Member

RESIGNED

Agens, F. F., Capt., USN
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Avila, Frank W., Lieut. CDR, USNR
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Holmes, J. R., Civil
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Wagner, John J., CHF ELECT., USNR
Walthers, Lorenze W., Associate
Ward, Phillip Lash, Civil
Westin, Lloyd Judson, Lieut., USNR

DROPPED FROM ROLLS

We regret exceedingly to report that it was necessary to drop 93 members from our rolls on December 31, 1957, in accordance with the By-Laws because of arrearage of two years in dues.

With much sorrow and regret it is necessary to report the death of the following, notice of which was received subsequent to the publication of the November, 1957, Journal:

Bagger, Frank E., Naval Member

Brown, William W., Naval Member

Davidson, LeRoy H., Naval Member

Edgren, Lawrence Lloys, Civil Member

Emmett, Charles G., Civil Member

Hoffman, Charles G., Civil Member

Holton, Henry J. V., Associate Member

Martin, George A., Naval Member

Pickering, Herbert E., Civil Member

Shepherd, Maxwell Robert, Associate Member

Smith, William T., Naval Member

Voges, Henry E., Associate Member

Walters, John S., Civil Member

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

ASSOCIATION NOTES

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

We have a new supply of lapel buttons, in the form of the Society's official seal. These may be purchased by any member for fifty cents ($0.50) each.

By decision of the Council the official coloring of the Society seal is as it appears on the cover of this Journal. This is a reversal of the colors on the old lapel buttons. The size, one-half inch in diameter, remains the same.

Any member who wishes to exchange an old button for a new one may do so *free of charge*. Just send in the old button with your name and address.

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c) Credit is given to the author.

d) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

APPLICATION FOR MEMBERSHIP

IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

(See reverse side for required qualifications for various classes of membership)

Date _____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $10.00 as my annual membership dues for the year _____ $8.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

For Naval Membership

Name _____
(First) (Middle) (Last)

Rank _____ File No. _____

Business connection and position, if any _____

For Civil Membership

Name _____
(First) (Middle) (Last)

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